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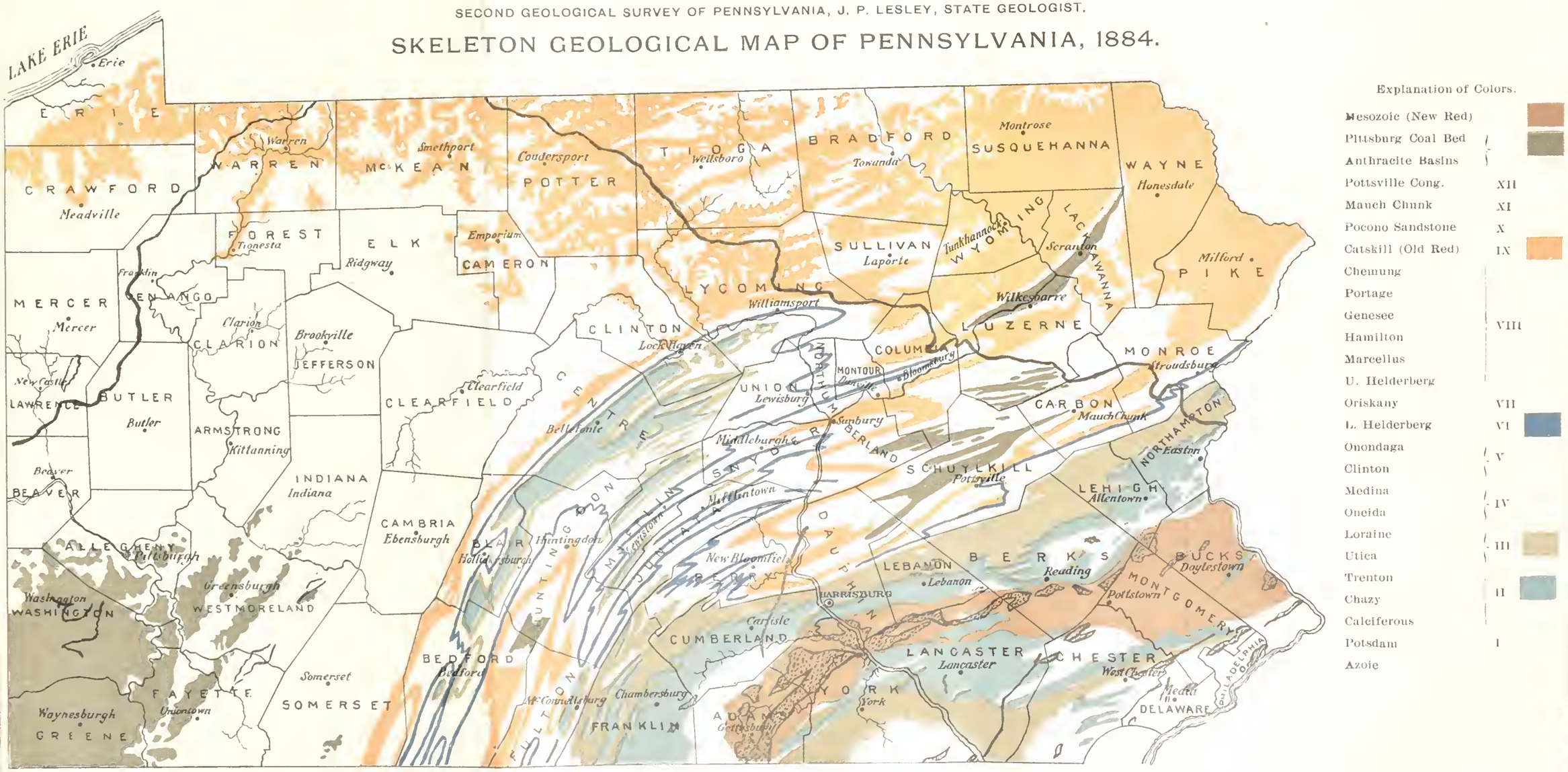
SECOND GEOLOGICAL SURVEY OF PENNSYLVANIA, J. P. LESLEY, STATE GEOLOGIST.

SKELETON GEOLOGICAL MAP OF PENNSYLVANIA, 1884.



Explanation of Colors.

Mesozoic (New Red)	
Pittsburg Coal Bed	
Anthracite Basins	
Pottsville Cong.	XII
Mauch Chunk	XI
Pocono Sandstone	X
Catskill (Old Red)	IX
Chemung	
Portage	
Genesee	
Hamilton	VIII
Marcellus	
U. Helderberg	
Oriskany	VII
L. Helderberg	VI
Onondaga	
Clinton	V
Medina	
Oneida	IV
Loraine	
Utica	III
Trenton	
Chazy	II
Calciferous	
Potsdam	I
Azoic	

COMMONWEALTH OF PENNSYLVANIA.

DEPARTMENT OF AGRICULTURE.

BULLETIN No. 69.

THE ROAD MAKING MATERIALS

OF

PENNSYLVANIA.

THEIR LOCATION, DISTRIBUTION AND COMPARATIVE MERITS; ALSO SOME SUGGESTIONS FOR THE CONSTRUCTION, MAINTENANCE AND REPAIR OF ROAD SURFACES.

BY

MAGNUS C. IHLSENG, E. M., C. E., PH. D.,
Prof. of Mining Engineering in the Pennsylvania State College.

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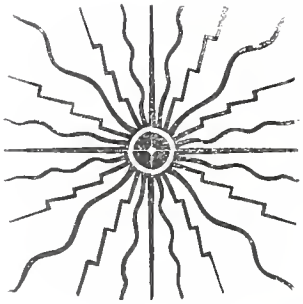

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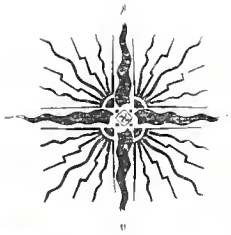

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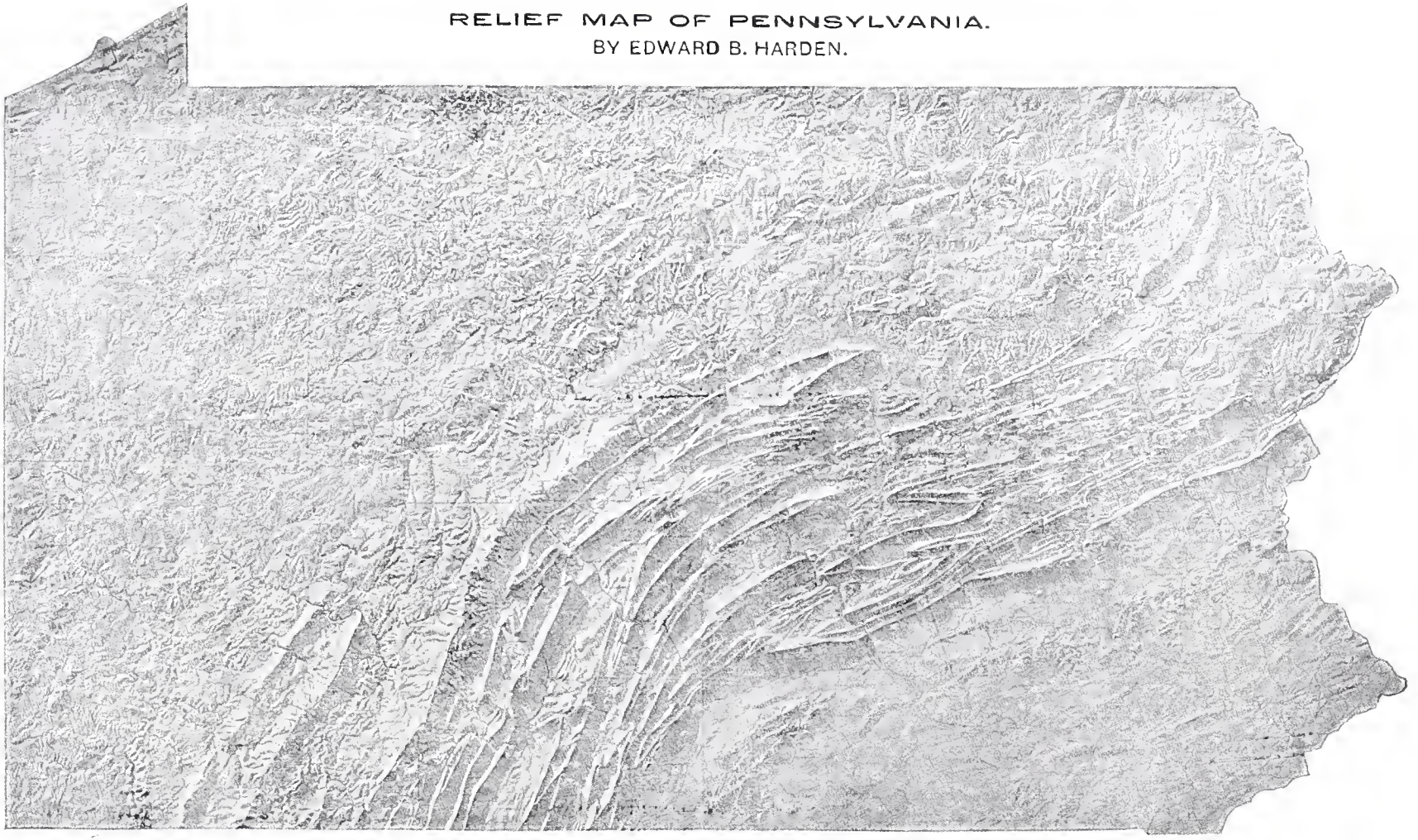
RELIEF MAP OF PENNSYLVANIA.

BY EDWARD B. HARDEN.



PREFACE.

Harrisburg, Pa., September 1, 1900.

The following Bulletin upon "THE ROAD MAKING MATERIALS OF PENNSYLVANIA," by Magnus C. Ihlseng, E. M., C. E., Ph. D., Professor of Mining Engineering and Geology in the Pennsylvania State College, has been prepared at the request of the Secretary of Agriculture, with the view of securing accurate data in regard to the supply of suitable road ballast and its location throughout the State. A preliminary investigation, made by this Department in 1896, published in Bulletin No. 66, showed that rock material was found in most of the townships of the Commonwealth, but at that time no careful or systematic study of the character of this material and its adaptability for road purposes was made.

The present Bulletin is to supply this information. Dr. Ihlseng brings to the study of this subject a degree of scientific and practical skill that will command his work to the attention and confidence of all who are interested in road construction. The facts which are here presented are of importance, not only in informing local authorities as to the value of the material in each locality, but also in making known to the State at large the resources of the Commonwealth in this respect, and so enable those who are endeavoring to frame suitable laws to secure good roads, to have at hand reliable data upon which to base their conclusions.

It will be seen that our State is abundantly supplied with the best road material known, and fully two-thirds of the roads could be permanently improved with comparatively slight cost, if those who have this construction in charge will select the best ballast instead of taking that which is soft and easily destroyed. Road construction is expert work. All of its operations from original location to final completion, should be under the management of capable men and not be left to ignorance and inefficiency to control.

State aid must be had before our roads can be what they ought, and competent supervising is a necessity before this money, contributed by the State, can be wisely and economically expended. This Bulletin is, therefore, commended to road supervisors and road builders in Pennsylvania, as a safe guide in the selection of road material, and it is hoped that its facts and suggestion may materially aid in bringing in the era of good roads and quick transportation to the country districts of the State.

JOHN HAMILTON,
Secretary of Agriculture.

Hon. Jno. Hamilton,
Sec'y of Agriculture,
Harrisburg, Pa.

Sir: I have the honor to hand you herewith a paper on the road ballast of the State. It was prepared during the present year after a personal tour over the entire State, and is intended to present the data relative to the distribution and value of the stones which are available for the surface dressing of roads.

Many of the rock formations were carefully examined and sampled, some of the important stone quarries were visited, many miles of the improved and ballasted highways were traversed a-wheel and some of the stone roads of New Jersey and Maryland were inspected. Correspondence with other highway commissions also furnish valuable information, and the city engineers throughout the State have contributed materially to the contents of the present paper.

Though the geological surveys of the State had fully exploited our rock formations, the latter received no subjective investigation as probable sources of our structural materials. The stone industry has only slowly developed notwithstanding our great abundance of material; and, naturally, our supply of superior road ballast has been totally neglected. But with the development of improved road systems in adjoining States and the eager local demand for comfortable connections between farm and town, the necessity for a technical knowledge of our available surface material is emphasized. It is the province of this paper, therefore, to indicate the merits and distribution of our road making substances, and the author trusts that it may prove to be a beginning in the direction of an acquaintance with the formations of the State and an inception of improved systems of road construction.

The State is not only abundantly and conveniently provided with serviceable road metal, but there is in one county alone—Adams—a supply of trappean material immediately available without deep quarrying, which will cover the entire 100,000 miles of State roads. It also possesses, as does some of its neighboring counties, ample supply of softer, inferior rocks. Not all the promising localities are easily accessible yet, and some favorable fields were not explored, but sufficiently detailed information has been acquired to convince me of the easy solution of the problem of road-stone supply. In most parts of the State the materials are so good, so abundant and so widespread that the lack of them can never be the excuse for bad roads.

Some physical tests were made of average samples, but the main reliance was placed upon the compound microscope to furnish the most useful information.

The author will welcome any suggestions or corrections that might be of service to our citizens in some future publication, that in the meantime tenders his services to your road officials if further tests are desired or more explicit information is needed. Thanks are herewith extended to those who have so kindly contributed to this publication, their names being quoted in appropriate places.

Yours very respectfully,

M. C. IHLSENG,

State College, Pa., September 1, 1900.

THE ROAD MAKING MATERIALS

OF

PENNSYLVANIA.

THEIR LOCATION, DISTRIBUTION AND COMPARATIVE MERITS. ALSO SOME SUGGESTIONS FOR THE CONSTRUCTION, MAINTENANCE AND REPAIR OF ROAD SURFACES.

BY

By M. C. Ihlseng, State College, Penn'a.

THE TOPOGRAPHIC DISTRICTS OF PENNSYLVANIA.

The map which is the frontispiece of this Bulletin, will reveal the area and location of the three topographic districts of the State. The lines marking them following, as near as possible, the ridges of the mountains determining the boundaries of the several districts. The line which is drawn over the northeastern corner, irregularly across the State and sweeping down into the Ohio marks the southern boundary of the glacial moraine which is composed of rock waste, boulders, sand, clay, gravel, scratched blocks of native and foreign rocks of all kinds, averaging fifty feet in depth. North of this extreme edge, the ice had left on its retreat, similar material which extends upward through the State of New York and into Ohio. In many places this material obscures the local geology. The heavy black line which zigzags its way through the middle division and finally passes out of the State on the south, in Bedford and Fulton counties, lines the outcrop of the durable limestone which generally furnishes good material. Inside of the territory bounded by it are numerous rock waves, revealing all grades of material which are referred to in the alphabetic list of counties. The dark belt traversing Bucks to Adams counties is of

red sandstone which furnishes the only sandstone of recognized reputation in the market for building purposes, but one which, though constituting poor road metal, contains numerous hills of volcanic rock extruded through planes of stratification of the sandstone. The darkened field along the border of New York comprises thin bedded, hard, flaggy sandstone of no value whatever for road purposes. The four counties almost exclusively covered by it are, therefore, totally devoid of serviceable material which is even tolerably good for roads. The other shaded belts on the map comprise rock formations indicated by the table on the right hand. This map is printed from a reproduction of the colored map of the second geological survey.

On the opposite page is a reproduction of an illustration taken from the report of the Pennsylvania State College, by whose courtesy this is incorporated in the Bulletin. It is a photograph of the large relief map of the State of Pennsylvania standing in the hall of the College, and exhibits with its light and shade some idea of the topography of the Commonwealth.

TOPOGRAPHY.

The State of Pennsylvania may be divided into three divisions, differing from one another in the character of the stone which is abundantly available for a top dressing to roads, and in the topographic features of the surface which determine the location, alignment, grade and permanency of the highways which are most feasible within their territories. Naturally, too, they differ in the comparative amounts of woodland and farming territory. The physiognomy of hill and ravine is determined by the nature and mode of occurrence of the rocks which immediately underlie the surface, and these depend upon the geological agencies which they have been subject. The road making materials of the State are the surface rocks, and within each of the three arbitrary districts are presented similar results of geological action, similar materials for the road master to employ and similar features for the highway engineer to combat.

The Allegheny mountains divide the State into two nearly equal parts—one field on the north and west, containing an almost level, unbroken bituminous region, and another on the south whose surface is corrugated with grouped strata that have been folded and crumpled into billows of great sandstone arches alternating with troughs of limestone or shale. The western field occupies about 55 per cent. of the area of the Commonwealth. This eastern half may again be divided into two districts by the high divide along the Kittatinny and Blue mountain range. (See topographical map.)

The western and northern district is a densely wooded territory whose average elevation approaches 2,000 feet above the sea in an elevated table land traversed by innumerable ravines and gorges. The banks are cliffed and terraced by durable sandstone caps roofing the softer beds of shale at intervals, in elevation furnishing exceedingly picturesque valleys.

The dip of the rocks is slight, scarcely perceptible in some places, except in the northeastern portion of the State. All the subterranean rocks for several miles in depth lie in position and order in which they were originally deposited on the oscillating bottom of prehistoric oceans. These sedimentary rocks have been undisturbed ever since. They have not suffered from any of the natural convulsions, but have slowly hardened under pressure without undergoing metamorphism or suffering any change that altered either their structure or their mass. Lying within the sphere of influence of the atmospheric agencies are only a succession of sandstone and shale with a few isolated exposures of limestone over the entire area as a mantle lies a loose mass of gravel and boulders which had been transported in earlier ages by glacial agencies from the north. The southern limit of this morainial matter is indicated on the map.

The middle district, which lies between the Allegheny mountains and the Kittatinny range, is composed of a belt of ridges and valleys about fifty miles wide, curving rapidly westward at the north and sweeping majestically around to a southward direction near the Maryland line. There are 2,700 square miles of stony linear mountain in its area. It is underlaid with a series of rock laid conformably one above the other, and, identical in sequence with those underlying the western district, at great depths. Originally they were laid horizontally contemporaneous with the coal measures of the western district, but at the time of what is known as the "Appalachian Revolution," they were compressed and folded into a series of rock waves forming parallel mountains of gigantic height whose western slope is a gentle one terminating with the Alleghenies, and whose eastern limit was marked by a vertical plunge to great depth. Floods, frost and heat have in a long process of time wasted the rocks until the mountains now existing, are but low cores and valleys through the softer rocks reveal a succession of limestone, sandstone and shale, neither the arches nor the basins are symmetrical "the lines of outcrop on the present surface revealing their shapes form a curious labyrinth of zigzags." The formations, therefore, in the processes of mountain making, have undergone a certain amount of metamorphism which have rendered the rocks more capable to resist the action of rains, floods, frost and heat than are those formations west of them which have not been subjected to the same pressure and heat.

The eastern district, which is more thickly populated than any other considerable section of the Commonwealth, is a gently undulating plain whose uniformity is broken only by a few clumps of the interrupted South mountain range and a few low ridges. Almost of its entire area is cleared and cultivated. The formations essentially comprise the rocks forming the primary nucleus of the continent extending from Maine to Alabama. Granites and gneisses cover the field with conformable layers of sandstone, limestone and shale, flanking them on the west and a belt of the very recently formed triassic sandstone, which furnishes a most excellent building material at the Kittatinny mountains. Traversing this belt along broken lines in many places are dikes of volcanic rock. Thus the eastern district presents to the builder and road master a great variety of massive as well as stratified rocks. Igneous, volcanic and sedimentary rocks occur in nearly equal proportions in the district, and are available as well as accessible for structural purposes.

The Telford and MacAdam Types of Roads.

It was in the beginning of the present century that Telford and MacAdam suggested methods of construction for roads after a long period of neglect, following the obsolete Roman methods of making pavement. And these typical road systems continue to the present day. The former engineer proposed to prepare a foundation bed covered with sand and broken rock, rolled and hammered into place and covered with large blocks of stone, closely fitted and laid, to furnish a regular surface arching traversely to the direction of the road. MacAdam proposed, instead of the top block pavement on the surface, a crushed stone layer which was compressed by traversing it repeatedly with heavy wheels or a roller of great weight until a smooth surface was formed. Roads built on these plans have, since the day of these engineers, been given the name of Telford or MacAdam, though they have degenerated somewhat from the original intent until now the latter term is applied promiscuously to any process of laying and rolling broken stone upon any roadbed.

MacAdam discovered the fact that almost any stone when broken into fragments would, with intimate contact and moisture, in a short time consolidate under the pressure of travel, and if freshly powdered rocks were added to the broken stone they would cement and set into a firm mass. The lapse of time has demonstrated this. It has been found since, that any broken material which has been firmly compacted and exposed to the natural elements will, under the beating of horses hoofs and the rolling of wheels, form a dust which, if not washed away, will penetrate with the rain into the

interior of the mass and upon drying become deposited to form a bond between the fragments of stone. If, too, the bits of broken stone be of sufficient hardness to resist the tread of wheels, a hard, dense, waterproof covering results which can bear up the load of constant travel.

From the engineer's standpoint, however, it is also equally requisite that the foundation be prepared and the grade and drainage carefully provided for. MacAdam's argument in the construction of a road was that nothing could make as good a road as the dry foundation earth, and that no matter what was over it, the ground after all is the road and must bear the weight of passing vehicles. The great object then to be sought in making a permanent roadway is a dry earth foundation with a roof covering of stone of such compactness as will form an impervious coating, and of such a thickness as will carry the weight upon it.

The integrity of the Telford pavement, therefore, depends upon the rigidity of its foundation, and its integrity cannot be preserved unless the interstices are filled to prevent the percolation of water. Few varieties of rock can be employed on top. The pavement is far more expensive than the macadamized road; it wears down very rapidly, probably because it is drier and the large stones act as an anvil under the hammer of the passing wheels to crush the underlying stone.

In the MacAdam road it is the superstructure which must receive consideration, and to obtain the cemented waterproof covering, the material must be properly selected and the surface rolled. It may be of any rock which will cement and is hard. It wears smoothly and uniformly except in places where the bond between the crushed material is broken at the time that frost comes out of the ground and continued heavy hauling cuts deep ruts along given lines. It requires little repair except to darn the few soft spots. The Telford, on the other hand, needs a complete resurfacing if worn through.

The Telford road or a MacAdam road with Telford foundation costs about $800 for each foot of width per mile of length.

The Telford surface of roads may be obtained by a variety of materials, though there is no material which can be said to possess all the desired requisites for a perfect pavement. Nevertheless, there are several classes of paving materials divided according to their character and the intensity of traffic which they are capable of bearing. That a smooth surface is the first requisite, is undoubtedly true, and a hardness of the material without wearing to a slippery surface is indispensable. In addition the interstices between the blocks must be filled with some impervious substance to protect the foundation. The construction is usually of sand, gravel or crushed stone base, spread over a rolled foundation

and a concrete of stone covering into which the dressed blocks of stone are rammed. Granite, sandstone and trap rock are employed for the latter purpose. If we broaden the term Telford, it may also include pavements of vitrified brick imbedded in a similar foundation, to that of natural stone. Philadelphia has granite, brick, rubble and cobble pavements, also slag-block—590 miles in all.

The pavements adopted and established for all streets and roads should be uniform. The following pavements are recommended: For streets having a heavy traffic, the dressed granite and Medina sandstone blocks are best suited; for streets other than those in the immediate business section, macadamized is to be preferred. Gravel roads are hardly recommended where the amount of travel is heavy unless they have been constructed under engineering advice. Vitrified brick pavements are meeting with favor in towns of considerable size and may even be employed in a single track way in the rural districts where natural rocks for macadamizing are not available. The general type of Telford road is more expensive in construction than that of macadamizing, which is much cheaper than the brick pavement and more costly than a gravel surface. Except in densely populated localities where the dressed stone blocks can be had abundantly and where labor is very low, the cost of Telford pavement would be prohibitive in all regions.

The Forces Which Tend to Destroy Road Surfaces.

The agencies which are engaged in the destruction of rock exposed to their action, whether in quarry face or on roadbed, include excessive rains, changes of temperature, frosts and winds. These forces are chemical and physical in their action, and in addition to them, the surfaces of roads are subjected to dynamic forces of travel, the beating of horses hoofs, the grinding produced by sliding wheels and the crushing produced by heavy weights. These forces result in abrasion of the surface, the formation of dust and the loosening of the particles of stone. The material which may be used for road surface, with different degrees of resistance to these forces are affected by them to varying degrees. Some of them are more readily affected by the dynamic forces of travel than by the natural agencies, though all are to a greater or less degree softened and destroyed by the natural agencies which everywhere prevail. Pennsylvania is particularly characterized by those climatic features which impair the conditions of carriage roads.

The Effect of Rain. In this State the average precipitation is about 10½ inches in the winter and in spring, and 9 more in the fall and in summer. These waters invariably contain solvent acids. Rain is often a dilute acid solution. As such it removes some of the

soluble portion of the stone with which it comes in contact. If the rainfall is not immediately carried away from the surface, it tends to soften the rock, penetrate into the interior, percolate to the foundation and there destroy the bearing for the ballast. A basin is produced by the sinking of the ballast and opportunity is offered for the formation of pools which further increase the damage. Though it has been stated above that any stone may be employed for top dressing of roads, nevertheless it will be understood that those which are soluble or possess soluble constituents must be inferior in quality. So, too, those which are porous or loosely coherent will have their integrity destroyed, besides admitting of the infiltration of a large amount of water to the natural foundation. A wet day, therefore, is the test of a road dressing material. The relative ability of the several rocks to resist this affect of water is discussed under the several varieties of road making materials, pages 20-24.

Frost. An admission of water into the interior of the surface covering is another effect still more destructive in regions which are subject to intense cold. The frost is a potent factor in rock weathering, and stones, which are porous or become permeable to water by solution of their soluble constituents, are rapidly weakened and crumble by the freezing of the entrained water; and such materials are utterly worthless for roads, if there is no cementing material in the incoherent rock to rebind the particles after thawing, or if artificial cement has not been added. This weathering agency in our climate demands the concentrated effort of the engineer's skill to overcome, for its influence is pernicious and all stone are subject to its attack. Compared with it the other difficulties of the engineer are comparatively trivial.

It is evident, therefore, that great care must be exercised to convey the waters as promptly as possible by providing the road with side gutters, and, if necessary on low ground, sub-drains. In Massachusetts where these essentials are observed no serious damage seems to have been done by floods and freshets. The expenditure in Massachusetts for maintenance has been for cleaning gutters and shoulders and placing on binding material upon the roads traveled by light wagons and where the binder has been removed by the wind faster than the wear of the stone supplies it.

The effects of changes of temperature upon the rock are not so serious, though the result is to expand and contract the mass, open crevices through which water may penetrate to the foundation and materially lessen the strength of the rock by loosening the constituent minerals.

The wind has an action upon a road of any description that is not inconsiderable. It removes the dust produced by travel which accumulates on the surface. It thus carries away not only the cushion which furnishes a relief to the traveler, but also the cementing material for the broken bits constituting the macadam. This wearing action, though less conspicuous than that caused by rain, is as persistent and even as great in amount. Soft stones, such as limestone, incoherent loose shale and crystalline granites are the sufferers from this cause and therefore undesirable for the top dressing to high grade roads. This film of dust can, however, be retained by constant sprinkling.

The weathering which results from water and wind action is therefore more pronounced upon porous stones like sandstone, those which are soluble, as limestone, those which are soft, like shale, and those which contain foliated mica, like gneisses and granites. These are undesirable for a hard road floor such as is required for heavy traffic. The road ballast must be impervious to water, its binding material preserved and its foundation kept dry by such means as the road master can employ. Upon this point engineers differ only as to the means which is best capable of attaining this end.

The Curse of the Narrow Tire.

The enemy to the integrity of the roadbed which is as destructive as any of the natural forces, but which is easily remediable, is the narrow tire. Naturally the effect of a rotating disk is to cut through and to shear aside the individual fragments in the covering, and, if the pressure is excessive, to produce a large amount of dust, and at the same time cut into the road covering like a knife. Ruts and dust are the consequent result. It has been shown from various sources that the pressure produced upon the area of contact on the road by a narrow tire amounts to more than 250 pounds per square inch and may reach a pressure of 1,120 pounds per inch of run. This is often greater than the pressure of the heaviest rollers which are engaged in constructing smooth roads, and no matter how carefully the macadamized surface may be built, a narrow tired, sometimes knife-edged, wheel is destructive. It has further been shown that only on a soft, sloppy and muddy surface, overlying a hard roadbed, does the narrow tire show to any advantage in the matter of economy of power as compared with a broad tired wheel. This condition lasts for but a very short season in spring, when the soft covering of the road will consist of sticky clay, immediately after a storm. Then the narrow tired wagon pulls more easily than the broad tire. These periods are also the seasons when little freighting is done.

A great variety of tests have been made to establish the claims of wide tire over narrow tired wheels. The most exhaustive and reliable series ever yet made in America, so far as the author is aware, were conducted by Professor C. M. Conner, of the Agricutural Experiment Station of Missouri. (Bulletin Number 39.) In Bulletin Number 12 of the United States Department of Agriculture, Office of Road Inquiry, are also given tables and results of tests.

It has been shown that on a macadamized street the same power drew 2,518 pounds on the wide tired wheels as was necessary for 2,000 pounds on narrow tires. On gravel road 2,482 pounds could be hauled with the same draft required for 2,000 pounds on narrow tires. And on broad tires the power which could haul 2,530 pounds on a dry, hard, smooth dirt road only drew 2,000 pounds on the common width of tires. The maximum weight that should be allowed per inch of width of tire should be 550 pounds.* The width of tire should be increased proportionately with the increase in the weight of the load. It must be understood that the width of tires do not affect the traction on hard roads, only the condition of their surface and cost of maintenance.

Width of tire of	2 inches	allowed load, including weight of wagon, 4,400 pounds.
	2¼	4,950
	2½	5,500
	2¾	6,050
	3	6,600
	3¼	7,150
	3½	7,700
	3¾	8,250
	4	8,800
	4½	9,900
	5	11,000
	6	13,200

For vehicles with suitable springs, the allowed load could probably be increased one-third.

One objection offered against the introduction of wide tires is the disadvantage at which it is supposed to be placed when required to run over the deep ruts made by a narrow tire, after the walls of these ruts have become rigid and the surface of the road worn comparatively smooth elsewhere. When only a very few individuals use broad tires the difference in pull is slight. But even one run of a broad tire compressed the covering sufficiently to materially decrease the draft of the vehicles passing along thereafter. Apparently "the ruts made by narrow tires are not the serious obstacles to the adoption of the broad tires that they have been believed to be." Be that as it may, certain it is that for the purpose of the road master every run of a narrow tire is an injury, and every run of a wide tire beneficial to the road. Again it may be suggested that if the fore and hind wheels be set on different guages, a still

*N. Y. State Engineer.

further benefit would ensue to traveler and road and they would become preservers not destroyers. A six inch tire is recommended as the most satisfactory width for farm wagons or road travel.

The destruction which ensues to the surface by the use of the narrow tire and the fact that a larger load can be drawn by the same power on a broad tire than on a narrow tire wagon, ought to convert the farmer in favor of the former, especially as its cost is not much, if any more.

The Road Making Rocks.

Rock Formations. The rocks must be capable of withstanding the atmospheric agencies and dynamic forces which operate upon the surface of a road and must therefore possess such inherent characteristics as will give the desired durability. The State is supplied with a variety of such material though they are of varied composition and texture. Classed into the three groups of sedimentary, igneous and volcanic, with different origins and of different constitutions, they occur in separate fields of the State. The middle and western topographic districts are entirely underlaid with sedimentary rocks; so also the western portion of the eastern district contains sedimentary formations. Those of the western topographic district have undergone no change since they arose from the sea and though of the same general composition as those in the middle district, are more loosely compacted than their equivalents which have been compressed in the process of folding the ridges between the Allegheny and North Mountains. Those which are in the eastern district have been subjected by natural convulsions; while the plutonic and volcanic rocks of the extreme southeastern portion of the State have undergone further change and have been subjected to the forces involved in the upheavals of recent time.

The Volcanic and Plutonic Rocks. The plutonic rocks are the oldest rocks in the State and by reason of the metamorphism which they have endured are recomposed in crystalline form. The volcanic rocks of the eastern district are more recent than almost all of the sedimentary rocks, and of course, than the plutonic rocks, and are certainly younger than the brown sandstones among which they are found, having been extruded from below in a more or less molten condition and rapidly cooled on the surface. The volcanic rocks are of a structure and composition much like the old igneous rocks. Both are more or less crystalline and complex. They occur in deposits which are massive. The distinction between the plutonic and volcanic rock is a scientific one, due to a difference in the manner and condition of cooling from a molten state. The members of the series of massive rocks which should surely be

designated as plutonic, are granite and gneiss. At the other end of the series, which comprises those rocks distinctly volcanic, we have lava and gabbro. Neither of the latter are glassy like the fluid or volcanic slags, but are basic and semi-crystalline. They may readily be distinguished in their physical appearances from the true granite. The plutonic rocks are coarse crystalline. The volcanic are fine grained. Their molecular arrangement was interrupted. Between these extremes are a variety of composite minerals resembling both of the extreme types, but differing from them slightly only in preponderance of one or other mineral. The later geologists are abandoning the distinction between the two groups because of the difficulty of drawing the line of demarcation between them. In any event these massive rocks are superior to the sedimentary rocks for road surfacing, and on pages 24 to 27 are given a few simple tests by which the road builder may distinguish between the different varieties of available stone.

The sedimentary rocks include the limestone, sandstone and shale in considerable range of composition, merging one into the other until it is a difficult matter sometimes to determine whether a certain stone shall be regarded as calcareous sandstone or a silicious limestone. These rocks are composed essentially of but one mineral and occur in layers, definite in thickness, easily followed with the exercise of a little care, and, though they may change somewhat in composition from one end to the other, maintain the same characteristics throughout. On the map on the frontispiece will be found lines indicating certain formations. These represent the places at which the formation appears on the surface. A given line, therefore, such as the heavy zigzag one, indicates the outcrop of a continuous formation which the geologists have called Helderberg. Above it and below it are other layers of sedimentary rock which lie in a given order and are conformable with it. Each may be traced in location by following parallel to the dark blue line wherever it may go. More extended maps, colored for each separate formation of rock, may be found in the county reports of the Second Geological Survey.

Road Stone. These rocks, sedimentary and massive, constitute the State's road making materials and are to be looked for only within the areas covered by the formations to which they are confined or where they have been carried by streams into adjacent areas. Broadly speaking, it may be said that the volcanic rocks are of the highest grade, and, with the plutonic rocks, are superior to the sedimentary rocks for the top dressing of roads. The road builder therefore has a choice of materials restricted to the group of substances accessible within his district, unless the exigencies of the occasion demand a quality of material superior to that which his

township affords; in which case he will select the superior rock for importation. Within his given district, however, there is so great a difference in the value of the stones composing the several layers, that he may find certain formations containing better limestone than are in the layers which have hitherto been employed. He may even find that some sandstones of his district may be applied upon the roadbed with better results than some of the argillaceous limestones which are immediately nearby. The properties which the several rocks have and the elements which they contain, tending to a high degree of durability, should be examined as well as the texture of the rock which would determine its ability to resist the weather.

The value of a rock for the roadbed depends upon its strength and durability, and in so much as it is impossible to prevent the action of the ordinary processes which tend to gradually destroy the surface, we must materially minimize their effect by suitable material and construction. A knowledge of the chemical composition, constitution and texture of the several rocks which are available furnishes a good clue as to their relative merits. But we cannot entirely depend upon a physical inspection of the rock, but must make such tests as will confirm the physical examination. This test may be either the examination of the formation in the field or mechanical tests in the laboratory unless we have experience to guide us.

Superficial Examination. It is the weathering qualities of the stone and the reliability of its constitutents with which we are concerned and this can be learned by a careful observation of the natural exposure at old quarry faces. Here the experienced observer may gain some idea of the wear, perhaps better than can be had from the ordinary tests hastily made in the laboratory, for the former represents the protracted tests of nature. Either of these methods lack definiteness and the results of one can be expected only in conjunction with those of the other. The unweathered stones might be compared with a natural exposure of the same formation in the field, but the degree of its durability cannot be entirely guaged by its appearances in the outcrop because of our insufficient knowledge of the length of such exposure.

The laboratory test, which is necessarily brief, must be severe and exaggerated if it is to furnish a guide in any wise approximating with that of the prolonged test of nature. These tests have only recently been entered upon. The knowledge which is at hand is meagre though facts have been collected from abroad and in America in sufficient numbers to afford ample information for the present stage of road construction.

Experimental Roads. Several States have established experimental roads to illustrate the need of construction and the value of the material employed for top dressing. Each State and district is easily supplied with a large variety of available materials, so that to be comprehensive, the tests must comprise a large number of measurements, at different parts of various roads, prolonged over a considerable peroid of time, if the results are to have definite value. The endurance of the several varieties of stone subjected to travel may then be observed and the comparative merits ascertained. France made a series of tests beginning in 1865 and repeated at intervals until 1893, in which year the measurements amounted to more than one-half million in number. They were compacted to determine the variety of the various materials of construction employed on the short sections of the road along the same line of travel. The record of traffic was made every thirteenth day of the year and the observations were extended over 22,000 miles of road. The traffic was classified and rated as follows:

1. Each horse hauling a public vehicle or cart loaded with produce or merchandise, 1.
2. Each horse hauling an empty cart or a private carriage, 1-2.
3. Each horse, cow or ox unharnessed, and each saddle-horse, 1-5.
4. Each small animal (sheep or goat), 1-30.

The results of this test have been confirmed by those in America, and information in this direction may be had from the office of Road Inquiry of the United States Department of Agriculture, which is so ably administered by General Roy Stone. The results obtained in Saint Louis a few years ago are quoted below:

"Sections of road were built of the different materials, 22 inches wide and 8 feet long. Two wheels, with tires 2½ inches wide and loaded to 2 tons or 800 pounde per inch width of tire, were made to pass back and forth over these sections by machinery. The heaviest traffic at that time in St. Louis was 75 tons per day per foot of width, and the average for business streets was 35 tons. Estimating the effect of horses' shoes at one-third of this amount, 50 tons per foot was taken as a standard. The samples were weighed before and after testing, and were subjected to an amount of wear by the wheels estimated to be equal to eight and a half years on the street.

"The total abrasion of the fire brick pavement was 9 per cent., or a depth of ¾ of an inch, but about one-half of the brick were broken. Asphaltum blocks under the same test wore 14 per cent., and but one was broken. Broken stone lost 1 per cent. under a traffic of 12.7 tons per foot of width. Broken stone and sand lost 1 per cent. under 16 tone per foot. Limestone block lost 1 per

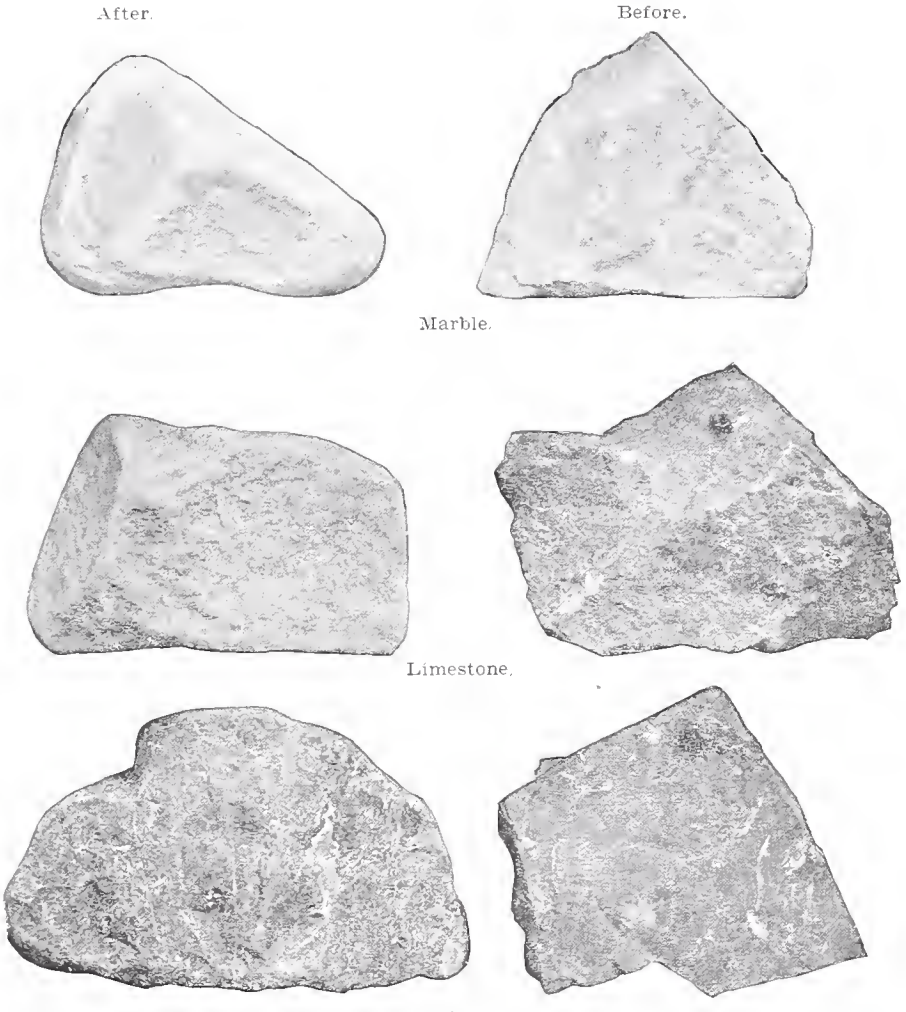
cent. under 4,400 daily tons per foot of width. Wood blocks lost 1 per cent. under 12,900 daily tons per foot, and the granite blocks lost 1 per cent. under 70,000 tons."

Laboratory Tests.—A durable covering may safely be expected from a material which shows its ability to withstand the elements and which behaves well under laboratory tests. As there is no absolute standard measure, however, the engineers have gradually adopted a set of ratios expressing the amount of wear which a rock undergoes when subjected to a given amount of force under given conditions for a stated length of time. These conditions are, of course, arbitrary, but if samples of stones intended to be used for road coverings are subjected to the same series of tests under the same conditions, their comparative merits may be ascertained from the results, not only among one another but also with those of similiar tests made elsewhere by other engineers. The stones are, therefore, arranged in order of merit according to their ability to show the same satisfactory results under these conditions in the laboratory. We will herewith describe briefly the tests which has thus been standardized.

Description of Tests of Road Building Materials.

Recalling that the qualities of a high-grade road-building material include strength, hardness, resistance to abrasion and a power of re-cementation, one will recognize that these properties must be tested by laboratory means similar to the natural agents. 1. The strength of the stone is ascertained by subjecting it to pressure, and the amount of such pressure is ascertained, from which may be determined the number of pounds of pressure which a square inch of area of the rock will support. 2. The ability to resist abrasion of grinding wheels and horses hoofs is ascertained by grinding the surface of a weighed amount of broken stone against one another, and weighing the amount of dust produced in a given time. This will show the amount of dust obtained from one pound of the rock. 3. The strength of the binding material in the broken stone is ascertained by moulding the dust produced in the above test for abrasion and subjecting the bricks to crushing test from which may be ascertained the amount of weight which the cement is capable of supporting by rupture.

There are tests for ascertaining the comparative merits of the road ballast; 1. To determine the amount of water which a given bulk of stone will absorb, to ascertain its porosity; 2. To determine the result of subjecting the saturated stone to an intense cold, by which its resistance to frost may be known; 3. The chemical analysis for determining the composition of the rocks in terms of the elements



Views of rock fragments before and after the abrasion tests.

By courtesy of Maryland Geological Survey.

composing it; 4. An examination by the compound microscope to see how the minerals of the rock are knit together and what is their condition as to weathering.

The Crushing Strength of the Stone. While the coherence of the particles is determined by their appearance under the microscope, the strength of the union is not known except by the crushing test. But it is hardly necessary to determine the exact crushing strength of a stone for it is rare to find one which will not be able to support at least 6,000 pounds to the square inch. Many stones range as high as 25,000 pounds to the square inch. The heaviest pressure or the severest impact which is likely to fall on the road metal is far below the resistance of even the lowest grade of stone, and, as a consequence, the matter of the strength of the stone to be used for roads may well be left out of consideration in the discussion.

The test for abrasion, or the relative wearing powers of rocks, is made in a rattling machine, which consists of a number of cylinders, 8x13 inches, mounted diagonally on a rotating axle and turned at a rate of 30 revolutions to the minute. Into these machines a weighed amount of broken stone (about 5 kilograms, or 11 pounds), of a size less than two and one-half inches, is rolled for about five hours. At the end of that time the samples are carefully sifted, dusted and again weighed, the loss in weight being the dust formed in abrasion. From this weight is determined a *co-efficient of wear*, to indicate the relative quality of stone. Its value is found by dividing 400 by the amount of dust formed per kilogram of rock. That is, a rock producing 40 grams of dust to the kilogram will have a co-efficient of wear equal to 10. The more dust it produces, the greater will be the co-efficient to wear, the softer the stone. Generally speaking, the co-efficient is inversely proportional to the amount of dust formed in the test. The year produced by this method is, of course, not precisely like that to which rock is subject on the road and does not measure the actual resistance of a rock to the dynamic agents, yet the test is valuable for comparative purposes. It assumes that the wear inflicted upon the specimens in rotation bears a definite ratio to that imposed by the traffic. The standard is taken at 20 grams because very few rocks furnish less than 20 grams per kilogram, that is, about 2 per cent. Illustrations opposite this page reveal the effects of the rattler test upon the hard diabase and the soft marble. Fig. 1.

The National Brick Manufacturers' Association made the following recommendation for rattler tests of paving brick, which is the chief test and should be made without shot of any kind. The charge of brick should not occupy more than one-sixth of the volume of the chamber of the rattler; the rate of revolution should be not more than 30 per minute, and the result is to be taken from the average of two distinct tests after 1,800 revolutions in each.

The crushing action of blows and the resistance of the rock to it can be directly measured in a testing machine which imitates the natural force in its effect.*

The cementation test has at last been standardized after many years of experimentation. Its purpose is to obtain a knowledge of the relative binding power of the dust of various stones used in road making. Though it has long been recognized as the most important property possessed by a first-class road metal, a knowledge of the processes involved in re-cementation has been a matter of considerable speculation. They probably involve: (1) Adhesion between the dust particles produced by capillarity; (2) the binding property of fine material possessing a small quantity of clay; and (3) the induration resulting from the deposition of calcite or other substances when the road's surface becomes dry, which were held in solution in that zone of the road which serves as a roof to the sub-structure; (4) capillarity existing between the walls of adjoining rock.

All stones appear to possess to some degree binding properties, though those which are decayed, as for example, most field stones, have lost much of the power of cementation. Experience has proven that the binding power of all powdered rocks is usually sufficient to hold together the faces of stone when rolled into place. The best method of measuring the strength of the bond is the impact test.

The stone is reduced to dust, run through a 100-mesh sieve and moulded wet into a briquette one inch diameter and one inch high, by pressure of 1,400 pounds per wet inch. Usually it requires an ounce to make such a briquette. It is dried for two weeks in the ordinary temperature of a room. The briquette is subjected to the impact of a two-pound falling hammer, arranged like a pile driver, to drop through a stated height as many times as it is necessary to break the briquette. With each impact upon the briquette the weight rebounds until the fatal blow is struck. This breaks the bond of cementation. The number of blows is counted and is taken as representing the binding power of the stone and is so used to compare this property in road ballast. The greater the number of blows necessary to overcome the cohesive strength of the pulverized and re-cemented rock, the higher is its grade.

For making the registry complete during the test, the hammer works automatically and can be dropped any desired height upon a plunger under which the briquette to be tested is placed. The plunger is held in two guides and attached to it as a lever, pivoted at one-sixth of its length from the plunger and carrying a pencil at its free end. The pencil has a vertical parallel movement five times

* The Deval machine used by the National School of Roads and Bridges of France, described in Report of Massachusetts Highway Commission 1899; also in Geological Survey Maryland III.

as great as that of the plunger, and its movement is registered on a drum against which the pencil presses. The drum rotates through a small angle at each stroke of the hammer; thus, an automatic diagram is taken of the behavior of the briquette throughout the whole test. The point brought out by this machine is the fact that, when the hammer falls on the plunger, if the material beneath it can withstand the blow, the plunger recovers from the downward thrust given it by the hammer; if not, the plunger stops at the point to which it is driven. In this way the number of blows previous to the critical blow, which destroys the bond of cementation, are accurately recorded on the drum.

A chemical analysis would materially aid the engineer or road builder in determining the suitability of a given rock for his purposes, in so much as it is the exact method of ascertaining the elementary composition. But it gives no clue to the combinations of these elements as minerals. The chemical composition of many marbles is identical with that of some limestones, but their properties are totally different and their merit far from equal; so, too, granites and lavas do not resemble one another in texture, strength or durability, yet their chemical composition may be alike. For various reasons, chemical examination is superseded by the microscopic, the latter may even eventually render the performance of a physical test unnecessary. For, when intelligently interpreted, it exposes to view the construction of the rock.

CHEMICAL ANALYSES OF SOME ROCKS.

THE MAJORITY FROM SECOND GEOLOGICAL SURVEY OF PENNSYLVANIA.

Limestones.	Carbonate of lime.	Carbonate of magnesia.	Insoluble matter.	Ferric oxide.	Locality.
Armstrong county, Upper Freeport,	96.45	1.45	0.83	0.96	Logansport.
Armstrong county, Ferriferous,	95.50	0.90	2.03	1.31	Madison.
Centre county, Freeport,	42.90	22.70	18.73	.....	
Chester county, Trenton,	54.10	43.30	1.95	0.61	London Grove.
Clinton county, Trenton,	95.07	1.04	2.66	0.26	Nippenose Valley.
Cumberland county, Trenton,	59.50	36.90	3.20	.....	Bellemonte.
Cumberland county, Trenton,	72.32	20.59	2.31	*4.43	Pine Grove.
Clarion county, Upper Freeport,	86.36	5.34	8.41	0.57	Mt. Holly.
Clarion county, Lower Freeport,	93.80	2.27	1.80	0.76	New Athens.
Clarion county, Ferriferous,	82.00	6.31	7.90	2.73	Reimersburg.
Clearfield county,	95.23	0.40	2.20	1.31	Porter.
Elk county,	93.81	1.71	2.10	.....	Glen Hope.
Elk county, Lower Freeport,	66.91	9.84	16.13	.....	Caledonia.
Elk county, Ferriferous,	57.32	8.85	21.25	7.94	Horton.
Franklin county,	91.78	1.81	3.35	1.71	
Franklin county, Ferriferous,	54.39	42.69	2.16	0.91	Mont Alto.
Forest county, Tionesta,	97.32	1.28	0.98	0.26	Williamstown.
Forest county, Tionesta,	40.64	1.17	55.16	2.12	Tionesta.
Jefferson county, above the Upper Freeport coal,	98.16	.....	0.77	†0.70	King of Prussia.
Jefferson county, Upper Freeport,	77.14	4.69	11.78	3.79	Big Run.
Jefferson county, Ferriferous,	89.10	1.61	6.17	2.14	
Lycoming county, Helderburg,	94.39	1.70	1.91	1.31	Brockwayville.
Lehigh county,	70.59	1.74	21.68	4.66	Jersey Shore.
Perry county, Chemung,	48.60	40.40	9.24	.....	Trexlerton.
Somerset county, Ligonier,	60.21	1.66	31.52	5.38	Newport.
Wayne county, Catskill,	53.74	.....	43.96	0.91	
York county,	64.39	1.81	28.80	4.15	
York county,	73.18	4.37	21.50	0.50	Dillsburg.
York county, Mesozoic,	93.87	0.96	4.30	0.30	Seitzland.
	44.95	5.27	14.01	†3.68	

*Alumina. †With alumina.

Sandstones.	Silica.	Ferric oxide.	Ferrous oxide.	Lime magnesia.	Alkalies.	Locality.
Dauphin county,	91.52	2.02	3.80	0.70	1.20	Hockersville.
Bucks county,	84.26	2.26	7.26	0.73	3.03	Morrisville.
Luzerne county,	94.00	1.98	.....	2.20	.....	Laurel Run.
Dauphin county, new red,	90.34	1.09	†5.08	1.12	1.47	Hummelstown.
Bucks county,	82.34	1.07	*4.35	0.95	1.50	Newtown.
Bucks county,	82.72	1.92	*10.29	0.27	3.90	Yardley.
Luzerne county,	90.36	.....	*3.35	2.00	.....	White Haven.
Shale.						
Wayne county, Catskill,	59.26	*19.08	*10.08	2.17	4.86	
Peach Bottom slate,	58.37	*21.98	10.66	1.50	1.90	
Dolerite,	60.25	3.36	†21.93	5.63	5.61	Goat Hill.
Dolerite,	52.82	5.45	†22.00	14.26	3.38	Brownsburg.
Diorite,	50.62	2.14	†23.26	17.03	4.75	Morrisville.
Pyroxenite,	46.38	3.03	†26.11	15.50	4.25	Vanardtsdalen.
Gneiss,	66.32	2.22	†14.07	9.38	4.82	Fallsington.
Syenite gneiss,	57.51	5.54	†20.94	8.67	3.43	Morrisville.
Granite,	65.42	0.21	†18.96	0.84	14.36	
Chlorite schist,	46.35	1.48	†25.44	20.92	0.58	Neshaminy Creek.
Slag.						
Armstrong county,	31.80	*12.58	0.63	50.76	.....	

*Alumina. †With alumina.

The petrographic examination of specimens is very important and constitutes the quickest, simplest method of classification. The unaided eye cannot clearly determine the composition of the rock, nor can even the expert mineralogist always determine the component minerals without auxiliary aid. Even if obtained, neither a chemical nor a mineralogic analysis will convey any information as to the internal arrangements of the component minerals.

The inspection of a mineral specimen by a lens would contribute some features which could not be observed by the eye. But a thin slice of the rock, cut, polished, mounted and examined by the microscope would clearly reveal the composition of the rock, its structure and the manner in which its several constituents are united. These properties the road master desires to know, and they can be quickly determined, easily prepared and at slight expense. By this aid the percentages of the several constituent minerals and the precise classification would be known. The writer believes this test is the most important of the series which should be applied effectively in the laboratory. It reveals also the causes for the differences in strength in the classes of road ballasts.

As will be seen from the accompanying illustrations, the volcanic rocks are made up of minerals very much intertwined, and this fact accounts, in a great measure, for the toughness of the rocks and the difficulty encountered in breaking them. In the granites and gneisses no such evidence is found, so they crumble more rapidly than the volcanic. Quartzite, which is made up of particles of quartz cemented but not intertwined, would then be more or less easily disrupted, according to the strength of the cement. The same, you will notice, is true of sandstone. Limestone will be seen, from the accompanying illustration, to be made up of particles of material of about the same shape as the crystallized cement which unites them. It is a compact rock and homogeneous because made up of small particles of fairly hard material, united by a cement practically as strong as the particles themselves. It, therefore, does not crumble though it is not necessarily strong.

These illustrations furnish a guide to the examination of rock with the compound microscope, and perhaps confirm to the reader the view advanced by the writer as to the value of the microscope for this purpose. It reveals the causes for the differences in strength; it shows the presence and amount of decomposition and condition always found in our rocks to a greater or less extent; it determines the character of the chemical changes, and may be said to give a partial elucidation of the factors on which the structural value of a stone depends. The sole objection to it is that it is not quantitative in its results, which depend largely upon the observer's accuracy. Compare the appearance of the massive rocks in Figs. 7, 8, and 9 with those of the sedimentary in Figs. 2 to 6 inclusive.

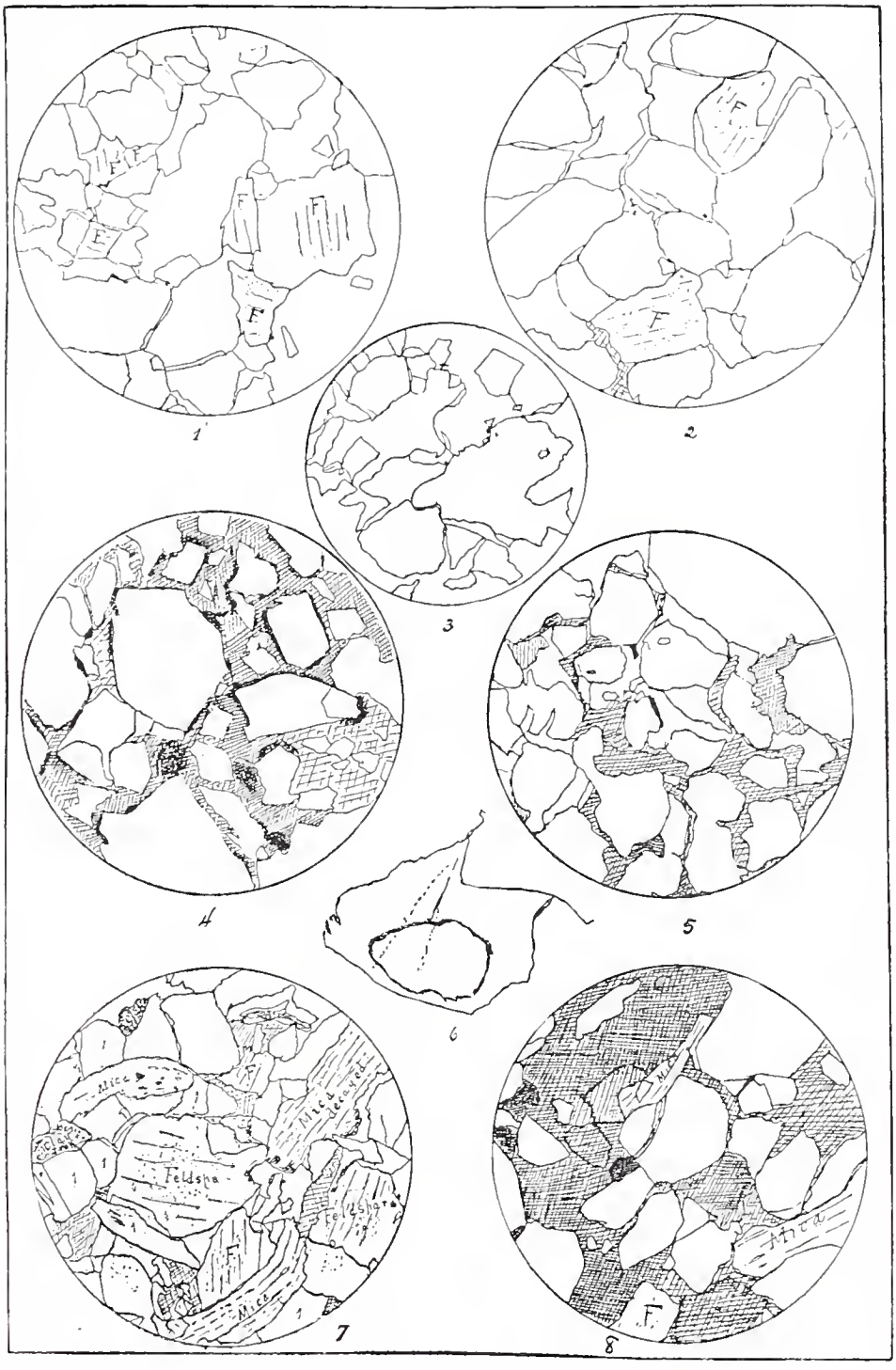


Fig. 2.—Microscopic sections of different brownstones enlarged 44 diameters:

No. 1.—Lumberville feldspathic sandstone—feldspar and quartz and quartz cement.

No. 2.—White Haven red stone, some feldspar, mostly quartz and quartz cement.

No. 3.—An enlarged granule from No. 2 showing its quartzitic character in spots.

Nos. 4 and 5.—Typical sections of the Hummelstown brownstone.

No. 6.—Enlarged view of single grain of the Hummelstown stone showing secondary quartzose character.

Nos. 7 and 8.—Sections of a well known New England sandstone showing its micaeous character.

F signifies feldspar; cross-lined areas aggregates of clay, fine quartz, and iron oxide; very dark shading iron oxide; colorless areas quartz.

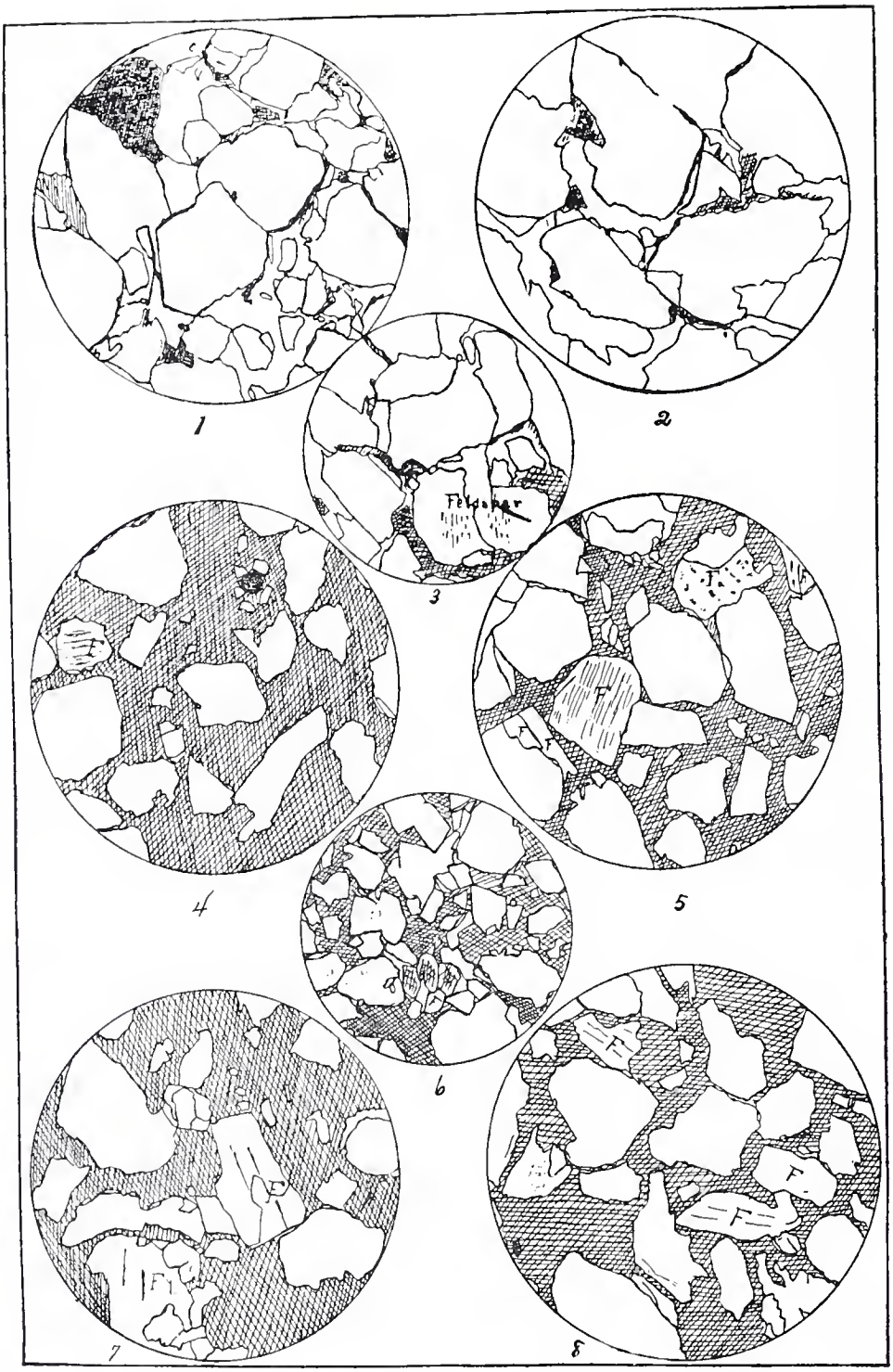


Fig. 5.—Microscopic sections of Hummelstown brownstone, magnified 44 diameters.
F signifies feldspar; cross-lined areas aggregates of clay, fine quartz and iron oxide; mostly clay; very dark shading iron oxide; colorless areas quartz.
No. 1—Pennsylvania Brownstone Co.'s quarry.
No. 2—Swatara quarry hard quartzose sandstone.
Nos. 4, 5, 7 and 8—Hummelstown Brownstone Co.'s quarry.
No. 3—An enlarged portion of a quartzose area from another part of No. 5.
No. 6—A less magnified portion, showing a larger area of No. 5.

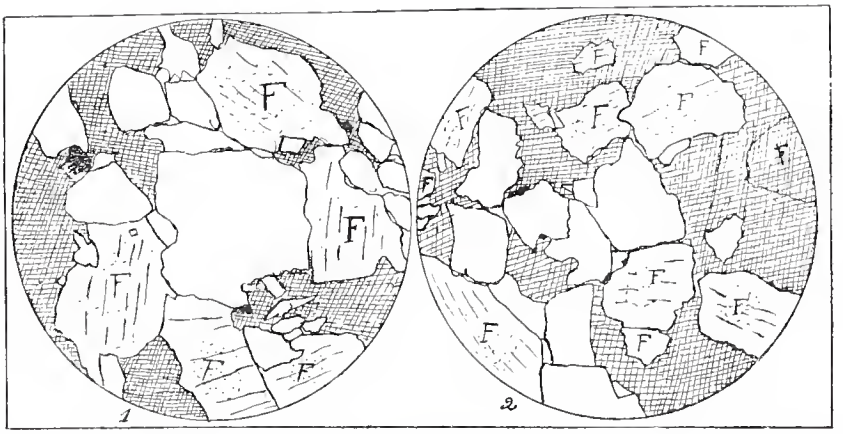


FIG. 6.—Microscopic sections of brownstone from Mitchell's quarry (1) and the Yardley quarry (2). F, is feldspar; the cross-line areas, aggregates of clay and finely granular quartz; the colorless areas quartz grains. Enlarged 44 diameters.

The following illustrations, on pages 31 and 32, Figs. 2 to 14, indicate what may be seen through the microscope by the examination of thin slices of certain rock. The separate minerals and crystals are indicated by letter or by shading. In Fig. 3, for example, the quartz grains are interlocked and the cement is revealed as calcite in the left hand section, and feldspar in the right hand section. No. 1, in Fig. 2, also shows a section of the same rock. Some views of

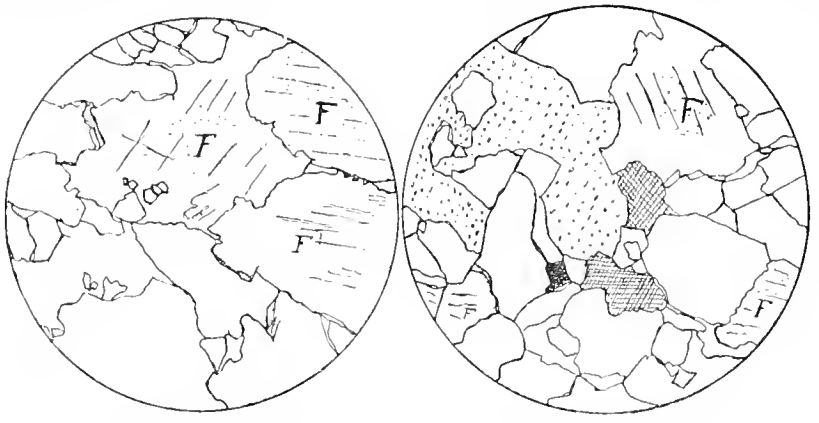


Fig. 3.—Micro-drawings of the Lumberville stone. F is feldspar.

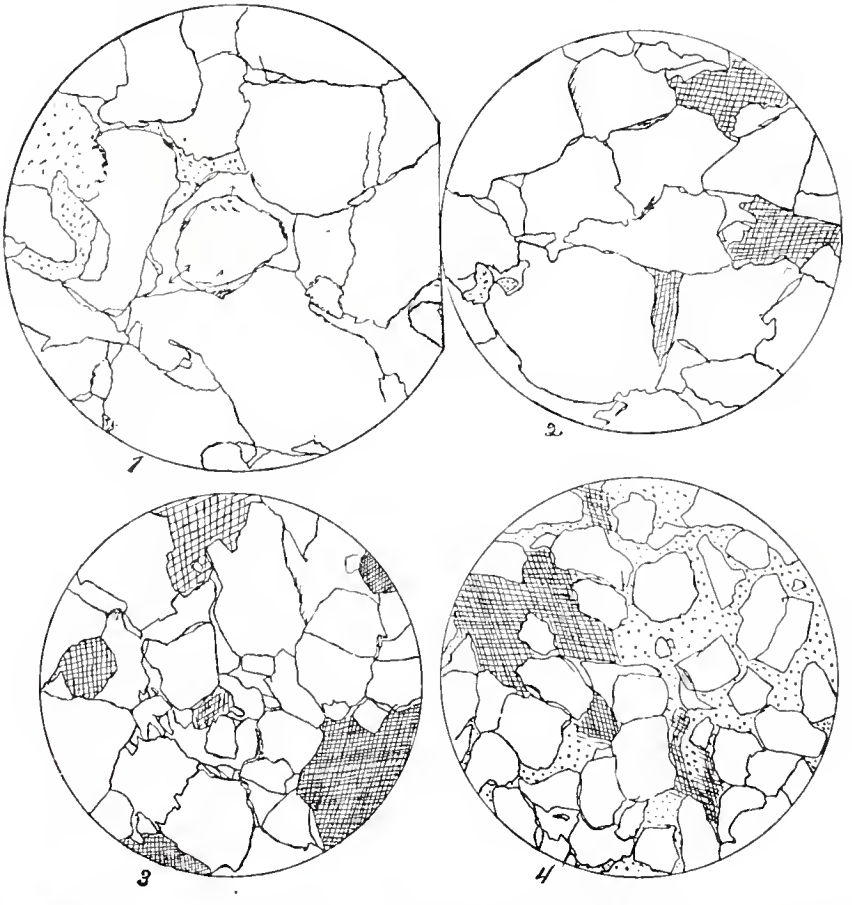


Fig. 4—Micro-drawings, enlarged 44 diameters, of the Mauch Chunk red stone. Cross-lined areas clay with finely granular quartz, dotted areas calcite, clear areas quartz. Typical quartzite grain in middle No. 1. No. 4, an exceptional calcareous area. All show the interlocking of the quartz grains.

the Mauch Chunk red stone are shown in Fig. 4, where increasing proportions of calcite cement are indicated in the samples progressively from No. 1 to No. 4. The interlocking of the grains is also well revealed. In Fig. 5, the well known Hummelstown stone is exhibited, as also in Nos. 4, 5, and 6 of Fig. 2. The uniform diffusion of the feldspar grains is apparent. The clay and iron oxide cement of the angular grains shows no lamination. The brownstone in Fig. 6 is softer and less brittle than that of No. 1, Fig. 2. Micaceous sandstone is exhibited in Nos. 7 and 8, Fig. 2.

In all of these drawings the letter F signifies feldspar over its dotted area. Aggregates of grey fine quartz or iron oxide are indicated by crossing hatching over the areas occupied by them. Dotted areas not otherwise marked are calcite. Very dark shading indicates iron oxide, and the colorless areas are quartz. The illustrations in Figs. 2 to 6 inclusive are copied by permission of the Pennsylvania State College from its publications on the Brownstones of Pennsylvania.

Figs. 7, 8 and 9 are reproduced by permission from the Bulletin No. 29, of the Office of Road Inquiry, U. S. Department, at Washington.

Plate II, Fig. 7.

DIABASE, SHOWING INTERLOCKED STRUCTURE.

By permission, from U. S. Department of Agriculture, Office of Road Inquiry, Circular No. 29.

Plate IV, Fig. 8.

GRANITE, SHOWING GRANULAR STRUCTURE.

By permission, from Circular 29, Office of Road Inquiry, U. S. Department of Agriculture.

Plate III, Fig. 9.

MARBLE, SHOWING GRANULAR STRUCTURE.

By permission, from U. S. Department of Agriculture, Office of Road Inquiry, Circular No. 29.

It is the *weathering qualities* of the stone and the reliability of its constituents more than its ultimate strength which concerns us. Both of these properties depend upon the manner in which the minerals are interknit and the strength of the union. The weathering quality depends also upon the chemical composition of the minerals more than it does upon the hardness or the toughness of union which determine its crushing strength. Stones composed of grains loosely held together are weak and their open pore space is great. They lack the coherence necessary to resist abrasion. If they are not held by a cementing mineral they cannot furnish an impervious road ballast, are easily crushed and also rapidly disrupted by the infiltration and freezing of water. When the particles composing the rock are interknit, the stone will be more durable than will one of granular structure. It offers little opportunity for the entrance of water and the minerals are not so rapidly dislodged. Even if the cementing material be weak, the latter stones furnish a better road material than would the first-mentioned incoherent rock. The re-cementation of the rock is more certain when the capillarity and the interlocking arrangements of the grains are high. Stones which are soluble, or possessing soluble constituents would be too readily destroyed by the rains, unless such dissolved materials are retained within the roadbed to furnish a bond for the rock. Stones which have minerals of differential degrees of disintegration are so variously effected as to crumble under the action of the elements. For this reason an inspection by the aid of a hand glass or a compound microscope is likely to furnish more serviceable information than would a mere test for the strength of union of the grains. The road surface must be firm and waterproof. It must be made so only by the use of a coherent aggregation having a strong cement. To determine the suitability of any rock for the purpose under consideration, the nature and behavior of its constituent minerals must be known.

The *porosity* of a rock is an important factor influencing the result of alternate freezing and thawing all its included water. All rocks are porous, but the pores are never of the same size, though they may have a general correspondence in size. By the capillarity of its pores, stones absorb water, and as this is objectionable it may be stated that, other things being equal, a stone of light porosity should possess a low absorptive power and would, therefore, be more durable to moist, temperature and frigid climates than when it would absorb a large amount. The absorptiveness of a rock is ascertained by soaking a dried sample in water for ninety-six hours. The increase in weight after saturation is ascertained and reduced to the standard ratio of absorption, which is the number of pounds of water which one cubic foot of rock will take up in that time. This rate is also

expressed in percentage, determined by dividing the weight of the absorbed water by the weight of the dry sample. It may be well to state here that this ratio is not equal to the volume relation which the term porosity expresses.

Hardness of the minerals is requisite in order to resist the crushing action of the wheels. This property is a variation wider than cementation. It involves the toughness of the elements as well as the toughness of the composition. A stone which has both properties is suitable for road surfaces for the conditions which affect endurance of each bit of macadam are similar to those effecting the entire covering. A mineral which is hard enough to resist the attrition of horses' hoofs and also will resist disruption will have the requisite strength for supporting the load. Hardness alone is not the only factor, for the mineral may be hard and yet brittle enough to be easily broken by a slight blow. This brittleness promotes crumbling under the impact of wheels. A quartz crystal is very hard; it is also very brittle. Sandstone, of which it is the main constituent, would, therefore, be totally unfit for road making, however desirable it might be for buildings where it would be subjected to a steady pressure. A rock composed of the hardest minerals or even the strongest minerals might be one of the weakest. It depends upon the size, manner of contact and arrangement. The diabases and diorites have a close interlocking of their minerals and, therefore, afford good service. The granites and syenites do not possess this arrangement or a cementing value as high as the traps. The climatic conditions must be considered in the selection of the stone, for one which would subserve the needs of a southern community would have no service in the northern States, where frost prevails. Nor need the porosity of the rock be considered if it is to be employed upon the arid plains of the west.

The texture of the rock is, of course, important, for the grains may be loosely aggregated or they may be interknit in crystalline form. The latter arrangement must contribute to an increased strength of stone. This relation is revealed by the table on following page.

Taking as a standard 1 cubic meter=1.3 cubic yards of basalt with a crushing strength of 1,500 kilograms per square centimeter (21,335 pounds per square inch), the equivalent necessary quantities of other stones are as follows:

Crushing strength. Lbs. per square inch.	Material.	Cubic yards, cubic metres, or quantity required, proportionate.
21,335	Basalt,	1.00
19,912	Basalt,	1.08
18,490	Diorite; aphanitic greenstone, melaphyr or angite porphyry, gabbro,	1.20
17,068	Granite, syenite, compact quartz porphyry,	1.32
15,645	Porphyry of the granite group,	1.59
14,223	Quartzy graywack millstone grit,	1.84
12,801	Graywack,	2.15
11,378	Quartzy limestone, compact new red sandstone,	2.57
8,534	Jura limestone,	4.00
7,112	Jura sandstone,	7.00
5,689	Chalky limestone,	12.00

The extraordinary decrease in durability compared with crushing strength shows the necessity of great care in testing and choosing stone for road-metaling purposes.

In the following table, average values are given, and the conditions of climate, traffic, etc., are the same in all cases. Under different other conditions it may be said that the differences in durability are less, the less the traffic and the more favorable the weather and the position of the road.*

*Stone, Vol. 14, page 380, 1896.

Description.	Strength of specimen, lbs. per square inch.	Strength per square inch, in pounds.	Weight of one cubic foot stone, pounds.	Ratio of absorption, per cent.
Granites.				
Biotite, glossy feldspar, grey,	56,558	14,137	164.74	0.31
Grey, feldspar in excess, mica, coarser,	47,752	11,938	167.86	0.26
Limestones.				
Dolomite, banded, blue streaks on white; very compact; fine grain,	62,832	15,708	179.09	0.07
Marble, color white, slightly seamed,	54,035	13,715	177.84	0.09
Joliet limestone, Ills., color dull grey; fine grain,	63,083	15,771	165.36	1.36
Sandstones.				
Hummelstown,	98,200	14,597	166.10	.....
Rockville, Mo., grey,	23,875	6,600	137.28	5.77
Light red,	29,656	6,849	139.77	4.44
Yellow, fine grained,	11,058	2,900	119.81	9.69
Pure light grey, fine grain,	39,710	10,337	181.01	3.12
Brown, fine grain,	17,593	4,333	126.05	8.99
Light pink, firm, very compact in structure,	66,601	16,818	151.01	1.13
Fine grain, porous,	30,763	7,179	134.16	6.00
Red, coarse granules of quartz enclosed,	40,212	9,385	160.37	0.85
Mottled grey, streaks of blackish clay,	37,699	9,616	142.31	2.42
Pinkish tinge, fine grain,	60,821	14,762	150.38	1.99
Mottled with spots of a yellow and a dark mineral,	52,779	13,064	150.38	1.52
Red, Laurel Run,	39,611	17,605	120.23	0.31
Red, conglomerate Trias,	15,582	3,895	148.03	4.43
Volcanic.				
Ash, grey lava,	29,656	7,414	141.65	3.18
Pink,	32,416	8,104	109.20	9.76
Gabbro,	46,244	11,800	.....	.....
Rhyolite,	88,000	27,132	165.10	3.266

Owing to the shortness of the time since the work was organized for this investigation, it has not been possible to prepare a list of tests upon the types of Pennsylvania road stone. The results quoted above, however, will serve as guide to the road master. Moreover, in the detailed account of the distribution of stones in the county will be found references to places where the best of the material is to be had, as judged from chemical test and microscopic examination. More than one hundred samples of typical rocks from over the State have been carefully examined by the microscope, but without any attempt to describe their appearances the conclusions were alone given.

The Minerals Composing Rocks.

The minerals entering most commonly into the composition of stones are quartz, feldspar, mica, calcite, kaolin, pyroxene and amphibole. These are aggregated in various proportions and in various ways to form rocks of different textures, composition, hardness and

strength. Others there are of importance and influence but not so freely distributed among the rocks as to seriously enhance or impair their durability.

Quartz, also called silica, is undoubtedly the commonest of these minerals; it is white and hard, but probably neither the strongest nor the most elastic. It may be recognized by its transparency and its slender pointed crystalline form. It is not affected by any acid and cannot be scratched by a knife, though it will scratch window glass. It is the essential element of sandstone or quartzite and should be easily identified by its behavior as noted. The sand of the seashore is quartz.

Calcite is the next most common mineral in rocks. It is either the result of deposition in the sea-forming limestone or dolomite, or it is derived from alteration of the feldspar in igneous and volcanic rocks. Its hardness, strength and elasticity are less than in quartz. The mineral is white, is soft enough to be scratched by a knife and will effervesce when touched by a drop of muriatic acid, or even vinegar, and is quite soluble in any carbonated waters, like rain. The limestone, dolomite or marble, of which it is the essential mineral, will also respond readily to the tests mentioned, though dolomite is the least soluble. The solubility of this mineral detracts from the permanency of the rock containing it when exposed to weather. When the dissolved mineral is removed by the flood, the rock decrepitates. If this constituent is not immediately washed away but remains instead on the road surface and percolates below, the subsequent evaporation of the water will result in its deposition in the interstices of the mass. It will then cement the individual stones and its presence becomes advantageous.

Kaolin is an important constituent of slate and shale, which rocks are of secondary origin. It is one of the softer minerals, light in color, and readily disintegrates under the action of the elements and is a product of the decomposition of feldspar, which, as we shall see, is a very common constituent of the igneous rocks. Indeed, the only exception of the most important rocks not containing feldspar are the quartzites and marbles, with a few limestones.

Feldspar, which is a very common mineral in the massive rocks, is softer than quartz, probably stronger and more elastic, and is little acted on by the common acids under ordinary conditions. It occurs in rhombohedral crystals, usually white in color. In the quarry, its decomposition takes place slowly, but owing to the fact that it is the usual constituent of the older rocks, it exists frequently in an advanced state of alteration. Weathering converts it into kaolin or clay, which rains and wind easily wash away. The slate, shale and clay roads are, therefore, easily effected by winds and rain and their surface are rapidly destroyed.

Mica is also a very common mineral, occurring most abundantly in metamorphic rock. It occurs in thin plates, readily cleared, providing easy passage for percolating waters by which the clusters are broken. The mineral itself is durable. It may be of any color, the dark ones being more durable than those of lighter tints. When it occurs in small isolated flakes—as it does in sandstone—the mineral is scarcely less resistant than quartz. But rocks containing large clustered mica are to be looked upon with suspicion for road purposes because of the ready separation and easy removal of the clustered mineral. The residual minerals are loosened and the rock will crumble. If the individual particles are large, the rock will very quickly be destroyed.

Some of the heavy, dusty roads in Lancaster county and near Philadelphia are covered with mica spangles.

Pyroxene and amphibole are two dark varieties of minerals resembling one another in appearance to the inexperienced, and have about equal strength and capacity to withstand abrasion and chemical influences. They are always distinctly crystalline, are composed of silica, iron, magnesia and alkalies, are easily seen in the rock, and, with or without mica, are the constituents in varying proportions, of the granites, gneisses and volcanic rocks. They are hard, without being brittle, like quartz, and are usually desirable elements of a rock for road-making purposes. There are several species of minerals under these group names, differing in chemical analysis.

Pyrite and marcasite are two iron minerals easily oxidized and decomposed, staining the rock brown or reddish. Their presence is, therefore, undesirable for building materials, but for road surface coverings, is not serious, unless the amount be very large compared with the bulk of the stone in which it occurs. The iron rust deposit, resulting from its decomposition, acts in a measure as a cement to bind the adjacent minerals of a rock or the broken particles of a macadamized road covering.

The Constitution of Rocks and Road Stones.

It is evident that the rocks will partake, in their properties, of the nature of the constituent minerals. They will be soft or hard, as the minerals of which they are composed are easily crushed or not. Their brittleness will be dependent upon that of the minerals or upon the state of aggregation of the individual components. Thus, the sandstone, which is composed of quartz, will be hard and brittle because of its chief constituent; limestone will be soluble, because of its predominant calcite, is easily acted on by acid waters; and syenite will be only so tough as the union of its two minerals can make it.

The color, also, of the rocks will be the result of the blending of the distinct colors of the mineral particles composing them. Pure limestone or sandstone are, therefore, white. The size and the distribution of the constituents determine the predominant tint of a massive rock. Fine-grained rocks will have a composite tint, though, on closer inspection with a hand glass, the separate minerals can be recognized by their different colors or shapes. Figs. 7 and 8.

The igneous and volcanic rocks are composed of masses of crystals of quartz, feldspar, mica and hornblende in different degrees, and the distinction between them is based upon the arrangement and relative quantity of the separate minerals. The road master may distinguish between them by the aid of the hand lense. He will find that the granites and igneous rocks show the minerals to be mashed together in the crystalline body like lump sugar, so that the separate minerals can hardly be distinguished, as in the enlarged figure, 8. The volcanic rocks have a distinctly spotted appearance like plums in a pudding, each crystal being individualized. The difference between the rocks is largely due to the rapidity with which they were cooled during solidification. The igneous, which cooled slowly, is completely crystalline, while the volcanic, which cooled rapidly, did not develop a crystalline growth, Fig. 7.

The Volcanic Rocks. First and foremost in importance among the road stones are the volcanic materials, which are uniformly desirable, and nearly all better than the best of other rocks and are therefore to be preferred in places where the cost is not prohibitive. These rocks go under the names of diorite, trap, lava, diabase, gabbro and porphyry. Though of volcanic origin they are not necessarily glassy or shiny. They are all rich in iron, dark in color, hard to break and composed of minerals uniform in strength and in resistance to the action of the elements. They are found in dykes across the country, extruding through the triassic sandstones of the eastern topographic district, or occurring in bosses and in palisades, with loose boulders lying on the surface commonly known as "nigger head." Most of the varieties are useless for building purposes, though they may do good service in foundations. They are close grained and the gabbro is particularly crystalline without interstitial amorphous matter. The grains are interlocked in such a perfect manner as to produce a rock difficult to disrupt, and when we recall the uniform hardness of the constituent minerals, it must be conceded that, as a rule, their resistance to abrasion should be uniform, with an equal wear and durability to all parts of the stone. The decomposition of these rocks yields substances having high binding power because of the presence of the iron and calcite which are released. They will then aid in consolidating the broken bits of stone on the road surface into an impervious, durable crust. Usually the

dike stones are better than the superficial volcanic rock in ratio of about 100 : 80.

As a class they will bear transportation for a considerable distance in competition with many local stones when a permanent road surface is desired. Road expert, James Owen* maintains that it is more economical to haul certain varieties of the volcanic rocks three hundred miles than to employ the local limestone.

Gabbro, which occurs in isolated localities in the eastern topographic division, undoubtedly furnishes the best of the road metal to be had in this State. It is richer in iron, more compact and contains less of the foreign substances than do the other volcanic rocks. Under the compound microscope the green augite minerals are revealed, as also is shown the perfect knitting of its component crystals. It is also better than the diorite, which is often mistaken for granite, though its quartz is hardly visible. It is often called greenstone. No substance in the State is better adapted for roads.

The granites are a crystalline, acid, granular, metamorphic series of rock, composed of feldspar, quartz and mica in considerable varieties of mineral constituence, generally in the above mentioned order of quantitative importance. Sometimes the mica is totally absent. The feldspar may be red, white or gray, and the quartz is usually a fine grained, colorless or white crystal. Locally, the granites may be of value, but they cannot bear the cost of transportation, for very little of the granite can be found whose feldspar is free from secondary alteration, and, if used at all, should not be taken from an old exposure to be used on the superstructure of a road. The quartz is brittle, the feldspar liable to decomposition and the mica is scaly and easily removed from place. The comparative absence of iron bearing substances, and the variation in the strength and character of the several minerals would operate to decrease the strength of the stone while the relatively less amounts of brittle minerals would diminish the power of cementation of its dust. Often dark horn-blende replaces the mica, then the granite is of better grade, but when the mica predominates, as it does in the gneisses, the rock is of inferior quality. The heterogenous character of the granites gives them a wide range of suitability. Fig. 8.

Gneiss is one of the granitic rocks and contains a large predominant amount of mica, rendering it inferior for road purposes or for building. It is recognized by the laminated appearance. The several minerals are aggregated in separate layers. The term gneiss signifies foliated granite, from which it differs only structurally.

*Transactions Am. Soc. Civil Engineers, Vol. XXVII, p. 609.

The gneiss roads just south of Pennsylvania line are not uniform in their durability.

Syenite, another of the varieties of granite, having no quartz but a large percentage of feldspar, is utterly unserviceable because of the high percentage of the two decomposable materials. It makes a good paving block and an excellent building stone where the qualities required are different from those demanded by a superior road metal, where the small broken rock has a large surface exposed to the intimate action of standing water.

As a whole, the granite materials are of second grade for road making purposes, and it is questionable if they are even as good as limestones. They have been subjected to heat and metamorphism, but the presence of the decomposable feldspar and the unequal resistance of their constituents places it out of the class of high grade road metal. They have, however, the advantage of being little affected by freezing and solution because they are compact and therefore absorb little water.

The sedimentary rocks are sandstone, limestone and shale. All when pure are white.

Sandstones are essentially composed of quartz cemented by a little calcite, iron, silica or clay and are of a variety in color and structure, according to that of its main constituent. The presence of iron gives it a pink tint or a brown, while the existence of organic matter is evident by the gray color. The grains of sand may be loosely or compactly cemented by the minerals named above, but as a rule, they are easily separated by a slight blow. This fact may be noted in illustrations, Fig. 2 to 6 and 12. It is rare that the cementing matter binds the grains so firmly that the mass does not easily break down under continued abrasion into incoherent sand. This is particularly true of the light colored sandstones which have essentially no good binding material. Sandstones having a large percentage of calcareous material are even less enduring than those having a clayey cement. Those possessing a ferrugineous cement are generally of a strong resistant nature. Hence, the presence or absence of a sufficient amount of good binding material in a given sandstone should be determined before using it upon the roads. There are sandstones which will make fairly good traveling ways and those may be found in the regions covered by a geological formation known as the Catskill (Hugh Miller's Old Red Sandstone). The rocks of the Triassic formation, consisting chiefly of red and brown sandstones, whose individual elements are united by an iron cement, are very serviceable for road building. The ferrugineous sandstones of the coal measures are very soft, loosely coherent and porous.

Owing to the very angular form which the quartz assumes when crushed, it mats well together, but the bits are not really cemented

into a mass so are easily dislodged by the blows of horses feet and the pressure of wheels. The addition of some foreign substance will remedy the difficulty. Clay or iron added in a small proportion to the sand may furnish the desired bond. It is unfortunate that this State is so extensively covered with sandstones which are so totally unfit for the bearing surface of roads, and the only specific directions which can be suggested for the northern and western districts, where these prevail, is to avoid light colored varieties as having no binding materials unless used with an admixture of limestone, iron and clay. As a rule, sandstones are porous and freely admit water to their interior, hence are easily disrupted by frost. In the dry season sandy roads are the worst, in the wet season they are bad enough and it is rare that there is just the proper amount of moisture to render the road surface firm. The weak spots along the Norristown and other turnpikes on the Triassic sandstone attest to this. Some clay puddled into the surface would strengthen the roadbed.

There are four sandstones within the State which are of sufficient quantity and distribution to furnish some road metal, though of very poor quality. These are, 1, the new red or Triassic sandstones, occurring in a broad belt in the eastern topographic district; 2, Mauch Chunk red sandstone, which is very hard and occurs along Lehigh Valley; 3, the Catskill formation, which is interbedded with the shales below and the white sandstone above, extending over the belt indicated by the shaded portion of the topographic map; 4, the medina sandstone, occurring midway between the two prominent limestones of the State, is a thick pronounced formation comprising the ridges of the middle topographic district.

The Triassic sandstone is fine grained, uniform and not too soft. It shows no disposition to shale when exposed to the weather; on close inspection is found to be fine grained with minute flakes of light colored mica and siliceous cement. This is undoubtedly the best variety of sandstones in the State for road purposes; the others mentioned being of varied texture and cementing material. All of the sandstones have practically no value for highway construction, lacking always some element requisite for a perfectly hard cementing rock. The conglomerate which marks the horizon immediately below all the coals has a siliceous cement, the indurated varieties being of only moderate wearing qualities.

Conglomerates, sometimes called "pudding stone," which consist of pebbles of sand, cemented by the same materials as those which bind the grains of the sandstone, have essentially the same properties and qualities as their allied formation. When the particles are angular instead of rounded, the likelihood of furnishing a good road surface is increased. The conglomerates of the eastern district of the State, having been subjected to greater metamorphic

agencies than those in the central portion, are of a little higher grade. They may be used a little more freely for road surface if employed in conjunction with some of the waste from the iron mines of their vicinity. Indeed, the abundant deposit of iron ore which occurred in the eastern and middle districts, too lean for furnace use, could be employed to great advantage as an artificial cement by being spread over the surface of the roads simultaneous with the conglomerate or sandstone. Still, they have only temporary coherence and have defied the best efforts at construction.

Quartzite, occurring in isolated areas of the eastern district, has been used locally with success as a road metal. It is essentially a sandstone, which had been subjected to a high heat, and is consequently extremely hard, tough, fine grained and homogenous. Some quartzites are too fissile for turnpikes. Fig 13.

Flint or chert, which is still harder than the preceding varieties of sandstone, is of local occurrence and used for road covering. In France, on account of its great abundance, is a very common surface material. This substance, however, does not occur in considerable quantities in original beds, but is largely mixed with lime—in fact it is a siliceous concretion of limestone. When exposed to the weather, chert decomposes slightly, a little being dissolved, leaving a spongy mass. This material furnishes a good road surface, hard, compact and almost free from dust. The best instance of this nature of roads may be cited from the mining regions of southwest Missouri, where the chert waste is utilized to make excellent road coverings. As the fragments of broken chert are angular, they are easily rolled into place, while the limy constituent serves to bind them.

Gravel is a siliceous material very largely used for road coverings, though it is not wholly recommended by the road authorities of either Massachusetts or New Jersey, where the unmixed gravel has been employed at the request of the local authorities to save expense. It shows marked effects of travel and "as the saving in expense of this construction over the cost of a macadam road will not equal to the cost of maintenance compared with the maintenance of a macadam road, screened gravel roads do not seem to be economical." * To be serviceable for road coverings, gravel must have the proper degree of coarseness, must have a matrix which will cause it to bind in the roadbed, and also must contain some soft mineral. As gravel is usually the detritus of some conglomerate of their formation and is not indigeous to the place where it is found, it is usually a washed product, free of any soft elements or those which might furnish a desirable matrix. Hence, such gravel as is found in the bed of a stream has no value for road purposes. Water worn gravel will not

*Massachusetts Highway Commission Report 1900, page 32.

key well. The loose, smooth pebbles would slip upon each other and allow wheels to sink in the roadway, and no amount of rolling would bind them to a union. If, however, some binding materials be mixed with it, or it be rolled with clay, a hard, firm packing may be obtained but even it will require watchfulness to preserve the surface.

Gravels, however, obtained from the table lands, associated with other softer fragments which have been displaced from their habitat, are capable of being packed promptly and firmly and with rolling may supply the quantity of powdered rock which is neces sary to knit the fragments together. This is true of the broad mantle of glacial waste which is so largely relied upon by the road makers of the northwestern district of the State. This foreign material contains iron bearing substances and detritus from the granites of Canada, which were borne down on to the soft rocks of the States south of the great lakes during the prehistoric times, on the flanks of the glaciers. In the eastern part of the State the gravels also have a wide distribution, and for practical purposes may be called a local deposit. They are loamy or arkose. Some of these gravels are better than crushed rock; in other cases, experience has shown the reverse to be true. They have considerable advantage over prepared macadam in that they require no crushing, though on the other hand they had been partially leached by water. The glacial transported material, even in its poorest form, is often usually better than what can be had from the underlying rocks. If care be taken in the selection of the gravel, that it is not too clean and free from iron and clay, a possibly durable surface is obtained after careful rolling. But as has been stated above in speaking of sandstone roads, the replenishment must be perpetual.

In the sections of the State where the gravel road must be constructed, it is highly essential that this form of improvement should receive great care in the selection of material. Assuming local stone in both cases, it can be built for less money than would build a macadam road, but its durability is not so high. It has given excellent service for the travel of moderately heavy wagons, but it would be useless for heavy traffic. The glacial gravel roads of Warren county have given good service, but now after five years will require entire reconstruction.

Care must be exercised in watching the loaders of the wagons that they do not throw more of the sand or clay, with which the gravel is buried in the pits, than has been determined upon for binding purposes. The amount of clay which should be mixed with the gravel on a sand surface, or the amount of sand which would furnish sufficient binder on a clay foundation must be determined locally. The great difficulty in reaching a decision lies in balancing

the elements. Whatever may be the mixture, it is one which would make a perfect road only in a given season. Roads of this kind, which are excellent in summer, might frequently be impassable in winter. Therefore no graveled roads should be laid unless the extremest of care is given them in the selection of material, the mixture and the construction. With the aid of a high degree of skill, New Jersey has succeeded in making excellent gravel surfaces through the pine districts. These should be the pattern for our road men of the northwest.

Limestone, which was formerly regarded as one of the best rocks for road surface, has finally proved to be unsatisfactory as a good, natural material. There are many grades of limestone of varied composition, and more abundant than any other stone in Pennsylvania except sandstone. Its distribution is wide, though the several varieties of limestone have different degrees of durability. It is easily crushed, is a cheap macadamizer, and binds well. Composed of calcite, with a cement of silicia or clay, it is easily acted on by water, quite soft, and though compact is easily disintegrated by the natural and dynamic forces to which it would be subject when used on a road surface. Its resistance to wear is low, but its cementing qualities are high. Its softness under the action of wheels results in the formation of a large amount of dust which makes the much traveled roads undesirable during dry and windy periods. For city use it is decidedly objectionable. The mud which it forms in the wet season is ruinous to carpets. Marble is the lowest grade of limestone for this purpose, being too closely crystalline. The fine grained varieties are preferable. Dolomite, which contains considerable magnesia, is softer than pure limestone. It cements well but is not so durable. When clay is present in any of the varieties, its effect generally is to improve its value as a road material, but no limestone is to be very much recommended where heavy traffic is present. It is always better than the aboriginal mud. Fig. 14.

Of the varieties of limestone, that which is geologically known as the Helderberg, is universally the strongest, having the highest resistance to wear, producing the least dust and possessing a superior cementing power. It is reported at several points in the anticlinal folds of the middle district. All points considered, it is more economical there than trap would be. That which is known as the Ligonier is next in grade and quality. Ranking well with it is the dark ferriferous limestone, occurring in the western counties of the State. The lowest grade of limestone is the Trenton, which is found in the valleys of the middle district. The dark colored limestones furnish a more agreeable surface for the traveler than do those of light, color which are so highly reflective in the summer light. If pinkish in tint they are still more desirable.

Marble is the lowest grade of limestone for this purpose. Being crystalline, they are very brittle, quickly turn to dust and are not acceptable for any road surface. Their structure is granular. Fig. 9 reveals the pronounced tendency to form rhombic grains and emphasizes the weakness of the stone. Marble quickly passes into dust. Its appearance reveals this deficiency.

Shales or slates are found as independent strata among the other sedimentary limestones and sandstones. The term shale is unfortunately not in as common use as is the indiscriminate slate or soapstone. The true shale is made of clay, hardened, and when pure is known as argillaceous shale. Its color may be from that of pure kaolin, which is white, to a dense organic color black with intermediates of pink or red, according to the amount of iron which may be present. The shale may also have an admixture of sand or lime, making it a sandy shale or a calcareous shale. In the eastern district there is in addition a shale which is largely micaceous.

Being composed of a material as soft as clay, the shale is usually crumbled in the process of weathering. It is the soft underlying layer of the hard sandstone ledges of the ravines in the western district. It is also the formation which furnishes the water courses or valleys in the middle district. Its inability to withstand the weather, as revealed by its behavior in nature, furnishes the clue to its suitability for road purposes. Wherever the shale occurs in sufficient body, the valley is characteristically broad, flat and fertile. This occurs along the Delaware, extending in a belt with the mountains across several counties in the eastern district. Of the three varieties of shales, the sandy shale is the most desirable for a top dressing. It may contain a sufficient amount of sand and clay to make a moderately hard surface that will pack well during three-fourths of the year. But it is soft and its absorbent qualities would detract from its service during the spring months. It is easily ground and forms a fine dust when dried, and a sticky, pasty mud when wet.

The calcareous shales often contain a small amount of lime or iron, and either of these acts as a cement, which, with sand or sand clay would make a fair surface. The argillaceous shales are the least adapted for substantial road covering because composed entirely of the one non-cementing material.

The distinction between sandy, argillaceous and calcareous shales is easily made. The first named is gritty, and when cut with the knife grates disagreeably; the second cuts smoothly like a piece of wax. No grit is felt when ground between the teeth. Calcareous shales effervesce with a drop of acid or vinegar.

Shales abound in every district though they are not by any means highly desirable, yet may nevertheless be employed to advantage

better than any other local stone which can be had at moderate expense. As a rule, the clay element in highway construction is undesirable. Yet in regions where the sandy shales predominate they may be acceptable, particularly if well sprinkled during the dry season, and the road scraper be conscientiously kept from it when repairs are made.

In the counties of the western district the sandy shales are found in abundance among the coal measures, and many of them constitute excellent material where the traffic is not heavy. They are usually of a dull color and therefore agreeable to the eye. They are not sufficiently valuable to transport, but are worthy of attention where they occur.

The shales which occur in the eastern district crossing the counties of Berks, Cumberland, Dauphin, Franklin, Lebanon and Lehigh, are capable of furnishing excellent surface when properly cared for. The material does not bind well but is moderately tough; affords comfortable travel and requires little work to keep up the condition of its surface. In the dry seasons of the year there are no pleasanter roads than those of Pike county between Bushkill and Point Jervis. This shale is geologically known as Devonian. It maintains its character throughout the belt across the Maryland line into Washington county, where similar roads are enjoyed.

However well ordinary shale roads may be maintained during the pleasant season of the year, they are not permanent, will require considerable repairs and are almost impassable in wet weather. Even in these regions a stone covering well rolled is requisite.

Slates are of the same composition as shales, but have been subjected to heat in the process of mountain building, and are therefore more compact than they were in their original state. Their behavior, therefore, is not different from that of the shale or its derivative, clay. Being harder, it would serve better but will require the addition of some cementing material to give it endurance.

In the opinion of the writer, clay, shale or slate is fit for road use only after being burned. In its raw state it has not the desirable elements for permanency. When mixed with sand in proper amount and burned in a kiln, the material should be used over the surface in the loose state or after being moulded into brick. Mr. F. Plumb, of the Illinois Clay Workers Association, suggested the construction of a traveling clay kiln for burning local product and spreading it on the spot. He proposed to dig the plastic clay by the roadside, passing it through a pug mill, expel the chemically combined water and render it non-plastic. This vitrified clay would then be used as a veneering on the surface. Six cubic feet would be required for each linear foot of road nine feet wide and eight inches thick.

Field Stones or Erratics. It is common practice to crush the loose boulders plowed up in the field or gathered along the roadway. This is a convenient, cheap and quick method of acquiring material for covering, but the practice is questionable unless the cobble has been selected with some degree of discrimination. The boulders are of the local formation, have been exposed long to the elements and, having lain on the ground or been buried in it for a time, would be more or less completely decayed from contact with the humic acids of the soil. Many are sound, however, because only freshly removed from place or sufficiently durable to withstand the action of the elements. But most of them are so far decayed as to be utterly worthless. They are the more unsuitable in condition according as they have been the longer exposed in the field.

Often their appearance may at once indicate how far advanced the rottenness is. In limestone regions the spongy nature or porous condition is evident. The sandstone cobbles easily fall to pieces when roughly handled. The micaceous rock will have a dusty sparking mass about it. A few blows with a sledge will best prove their unsoundness. Those which crumble readily and powder freely may be rejected safely. If there are many such boulders that fly into fragments, the supply may be passed by as affording material which, compared with the rock in place, is at least unfit. Rocks breaking into small blocks along a pair of parallel cleavage planes may be accepted as, at least, in a sound condition.

Iron Ore. At many points in the limestone regions, as well as near the massive rocks, are found numerous deposits of bog iron ore and other bedded iron ores whose value for road making is not to be ignored. Many of these deposits have ore too lean to be worked in the furnace, and there are in addition waste heaps of the old iron mines which afford abundance of material. These substances are suitable for road covering as cement to the sands or sandy shales which occur in their vicinity and which are likely to be the sole available road coverings. The iron ores are particularly useful for binding the bits of stone together, and as the cost of their extraction is quite low, they are mentioned among the list of road making materials. They cannot be used alone and are serviceable merely in mixtures.

Slag. Blast furnace slag has been employed in its crushed state for road covering. It contains the chemical elements for a good road material, though it is too freely soluble when under the water for a prolonged period. It competes well with the low grade local limestones, but will not admit of hauling a great distance. Its rank in the list of materials is below the best granite and above most of the limestones. In New Jersey several experimental stretches of road were veneered with it and in a few regions it was

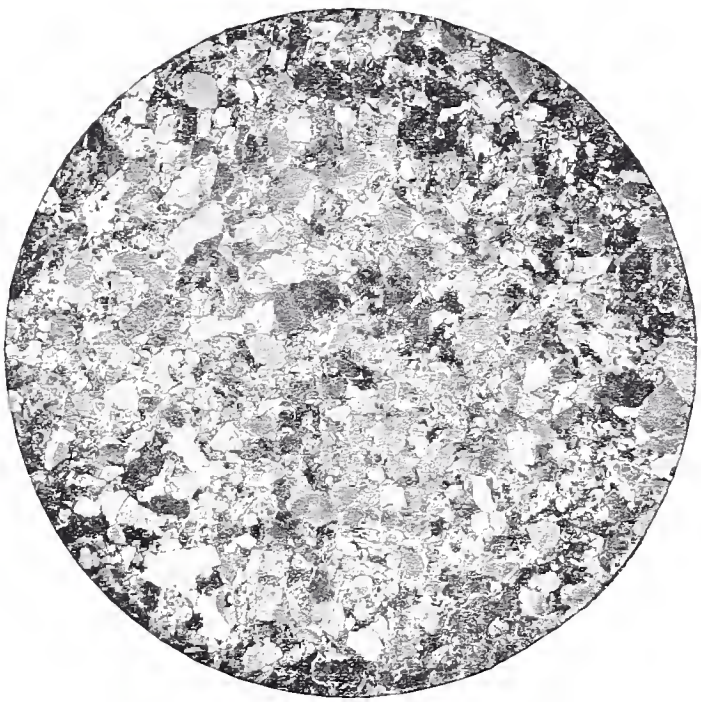


Fig. 10.—Gneiss. Photo Micrograph of Rock Section.
Printed by courtesy of Maryland Geological Survey.

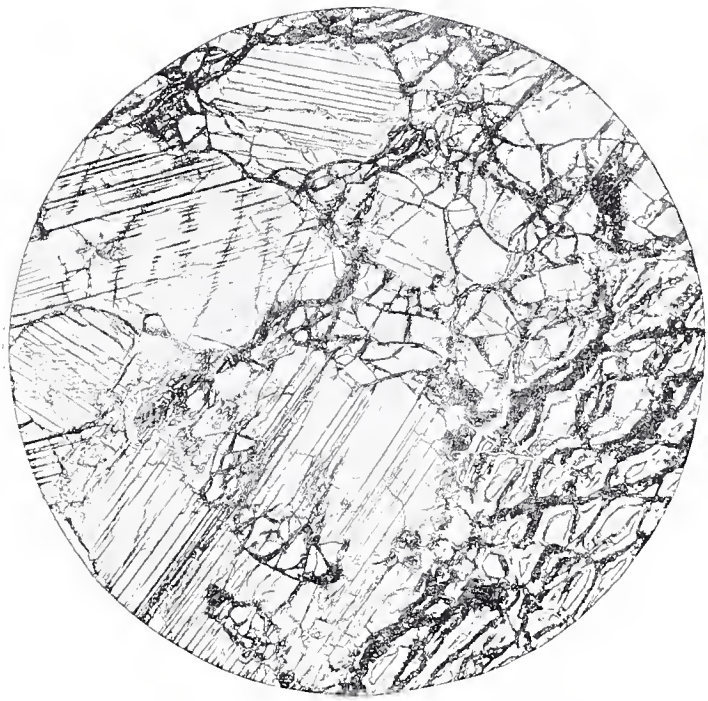


Fig. 11.—Photo Micrograph of Rock Section—Trap Rock, Serpentine.

Printed by courtesy of Maryland Geological Survey.

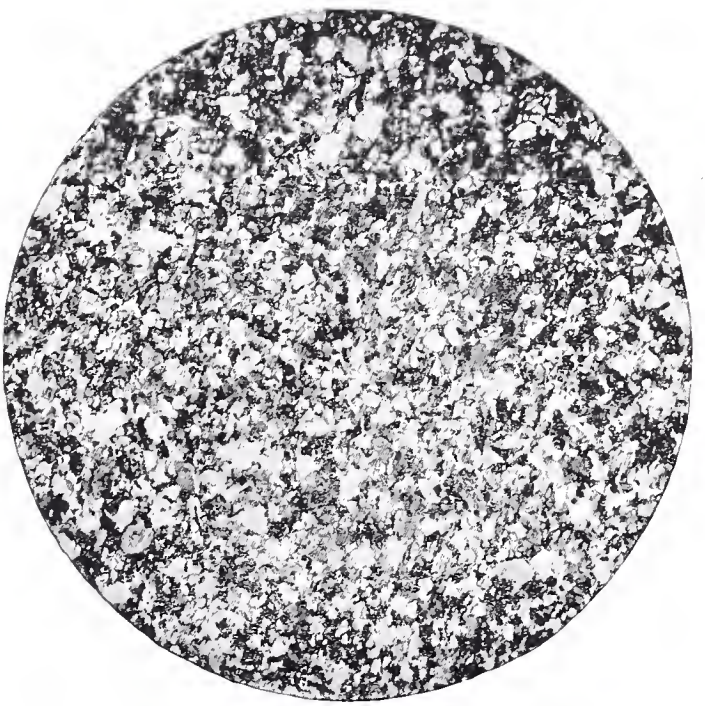


Fig. 12.—Photo Micrograph of Rock Section of Sandstone.
By courtesy of Maryland Geological Survey.

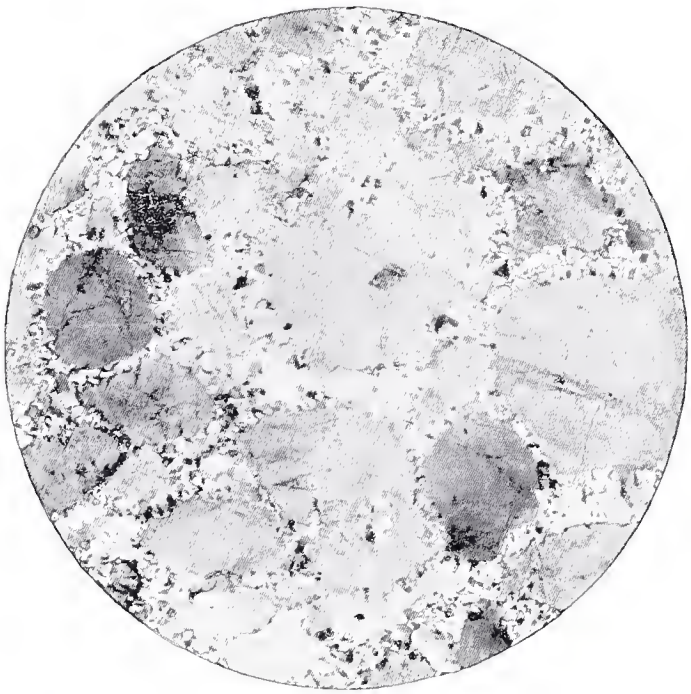


Fig. 13.— Photo Micrograph of Rock Section—Quartzite.
By courtesy of Maryland Geological Survey.

Fig. 14.—Photo Micrograph of Rock Section—Limestone.
By courtesy of Maryland Geological Survey.

used as a foundation material for trap surface. In those instances it had proved of excellent quality. In one locality it costs 44 cents per square yard, laid, while the high grade stone costs 54 cents.

The slag blocks used in Philadelphia, laid on a Telford foundation, are exceedingly durable. They, however, make a very slippery surface, which is decidedly unsafe.

BRICK PAVEMENT.

Brick pavements are quite extensively used in our western cities though they are still in an experimental state. They are laid on a foundation of 4 inches to 6 inches of cinder, sand or concrete, thoroughly rolled, over which has been spread a thin cushion of sand from one to two inches thick. On this the bricks are laid flat with the longer dimension parallel to the street. They are rolled, surfaced and then grouted by working sand, asphalt or cement between the joints to act as a filler. The bricks are of a peculiar kind of hard burned quality different from the common brick. The clay from which they are made is one which is incapable of fusion under a high heat, having little lime, magnesia and the alkalies with less than three per cent. of iron. The clay should not effervesce with acids, should be capable of making, with water, a paste that is plastic, and when dry should make a solid mass, breaking when struck into scales. The clays having a soapy feeling are of better quality than those which are rough to the touch. As a rule, it may be said that the pure fire clays and shales which occur in connection with the coal beds are of the best quality for vitrified brick.

Almost the entire region included in the northwestern topographic district of the State is underlaid by coal measures. These contain desirable clays for brick making.* As this region is a district over which little natural road making materials are to be found, it would seem that the utilization of these shales by the erection of local brick kilns would establish an industry of no small amount and furnish a durable road covering in the region where good surface is utterly impossible without imported rock. According to the data

*The School of Mines of The Pennsylvania State College has issued a free Bulletin describing the clays and clay industry of the western section of the State and has in preparation another which will comprise the north central region of Pennsylvania.

obtained from 26 city engineers throughout the state, the prices paid for the pavement varies from $1.10 to $1.60 per square yard, including gutters, curbs, &c. The cost is influenced by a wide varieties of factors, that of transportation being the greatest, but it would seem that municipal enterprise should establish kilns for baking brick out of the underlying shales and thus reduce the cost per thousand below $10.00, which appears to be the minimum figure. If it is possible, as the author is disposed to recommend, brickways might be laid into county districts; a width of seven feet could be laid on a secure foundation at a cost of not to exceed $2,500 per mile. The popularity of the brick pavements in the west has led to their rapid extension to the borough lines, and in regions of moderate traffic this price would not be excessive when one recalls that the life of a brick pavement is about twenty years and the annual cost of repairs is less than $60.00 for the first five years. The loss in broken brick average between 2 and 4½ per cent. for eleven cities, where there has been much handling.

A very good example of a seven feet country brick way is furnished near Franklin, where two miles of such a surface is laid along the river; and now, after three years, is in excellent condition, having had no repairs during that time, notwithstanding the heavy traffic to which it has been subject. It was built by excavating to a depth of 6 inches on one side of the center line of the road and spreading 2 inches of sand for the brick, with a sand filler on top. The soil on which it was located is a gravelly loam to hold the pavement in place it was curved with a strip of white oak projecting two inches above the pavement on both sides.

The ordinary city construction includes a foundation 14 inches deep. Into this is laid 8 inches of broken local stone, 2 inches of sand and 4 inches of brick.

Brick pavements are as strong as granite and are noiseless, fairly clean and more durable than the best limestone macadam. With a minimum traffic of three tons, brick is superior to granite. It requires no high order of skill to lay and repair it. The disadvantage arises from a lack of uniformity in the material and the risk of introducing some brick which are soft and porous. These objections, however, may be obviated by a careful inspection of the material used. Below are given a number of tests made upon brick which were of a size 3—4 by 3—4 by 1½ placed on end between pieces of soft pine, about ¼ inch thick and ground to a true size on an emery wheel.*

*Engineering and Mining Journal, William Kent.

	Specific gravity.	Per cent. Absorption.			Crushing strength, lbs. per square inch.
		Three days.	Five days.	Ten days.	
No. 1,	2.185	3.79	3.92	4.06	10,120 minimum. 12,920 maximum.
No. 2,	2.305	3.18	3.19	3.37	9,893
No. 3,	2.227	1.87	2.20	2.70	9,386
No. 4,	2.287	3.10	3.12	3.82	9,361 minimum. 10,000 maximum.
No. 5,	2.415	7.67	7.96	8.71	9,173
No. 6,	2.360	7.11	7.48	8.70	8,862
No. 7,	2.286	3.25	3.38	3.64	.....

For comparison, the following tests of common building brick are given. Results in pounds per square inch:

Good Average Haverstraw Brick, Tested by Mr. Abbot.

	Maximum.	Minimum.	Mean.
Whole brick on end,	3,060	1,600	2,065
Half brick on flat side,	4,153	2,669	3,371
Half brick on small side,	6,400	2,900	4,612

Experiments by Prof. Pike, Minneapolis, Minn.

St. Louis, Mo., brick, flatwise, 6,417 pounds; edgewise, 4,080 pounds.

Hastings red brick, hard, 2,017 pounds; medium, 2,012 pounds; soft, 1,748 pounds.

A series of tests by the National Brick Makers' Association is quoted below from their report of 1897, page 165 *et seq.*

Designation of sample.	Clay Material Used.	Dimensions of Brick.	Per cent. loss in rattler test.	Per cent. gain in absorption test.	Specific gravity.	Modulus of rupture in cross breaking.
1	Shale,	8 x3¾x3	13.72	1.52	2.41	26.69
2	Shale,	8 x4 x2½	14.53	1.15	2.34	36.63
3	Shale,	8 x4 x2⅜	11.45	1.17	2.37	36.19
4	Shale,	8¾x4 x2½	12.94	1.83	2.33	34.98
5	Shale,	8¾x4 x3½	10.80	1.72	2.35	31.04
6	Mixture,	9 x4 x3	9.86	4.09	2.24	28.42
7	Shale,	8 x3¾x2½	18.98	2.05	2.33	24.79
8	Shale,	8 x4 x2½	13.34	0.92	2.41	37.80
9	Shale,	8 x4 x2½	10.12	1.05	2.36	36.18
10	Shale,	8 x4 x2½	12.74	1.85	2.28	29.58
11	Shale,	9 x4 x3	10.26	2.48	2.27	30.56
12	Mixture,	9 x4 x3	11.95	2.86	2.22	24.28
13	Fire clay,	8¼x4 x2½	10.87	4.78	2.20	32.21

The Results of Microscopic Examination of Specimens from 150 Localities.

Made by Mr. W. L. Affelder, at State College.

The Diorites from Chester, Berks and Adams counties was almost identical in all cases. Dark, mottled and compact, the quartz is a cementing bond and the feldspars are unaltered. The Diabase of Adams county shows cleavage and zonal structure. The microcline reveals the characteristic "window grating" structure and the feldspars are without signs of decomposition. The Diabase from Berks county shows the olivine altering to serpentine though the stone is still in good condition. The serpentine from Thornburg is not quite completely stable, some olivine crystals being still present. All the samples which were examined show the presence of some of the soft talc. Gneiss from St. Peters is composed of interlocked crystals in an excellent state of preservation.

The Montgomery county marbles show a calcite cement in minute crystals. The Coplay limestone is fossiliferous. The Avondale marble contains nfica. The marble of Wrightsville is too friable for roads because of existence of grey calcite crystals in advanced state of alteration. The valley limestone of the middle topographic district is highly magnesian, fine texture, with calcite cement and abundant fossils. The Lower Helderberg limestone of the hills of the middle district are typical calcareous deposits, fine grained and strong, with enough iron present to stain the stone on exposure. The limestone of Erie county is of oolitic structure with a siliceous cement. The fishpot limestone of Greene and Washington coun-

ties, so extensively used for roads, is made up of minute crystals of calcite broken by numerous fossil remains and a thread of larger crystals of calcite.

The sandstones of the ridges and hills in the middle district are quartzitic and strongly coherent. Iron and mica occur in them all to slight degree. From Tioga the old red sandstone contains magnetite. Some hornblende is discovered in the Centre county Catskill sand. That from Lanesboro contains some clay as well as magnitite. The Triassic sandstone of Lambertville contains a little calcite and siliceous cement to the partially rounded grains of quartz. Some ferrite occurs in the Hummelstown stone.

Results of Tests.—An examination of the results obtained by prominent engineers and neighboring State's Geological Survey upon the various rocks has revealed great differences in the resistances to the several forces to which they were subject. As may be inferred from what has already been stated in the text above, rocks of the same class would manifest as wide difference of value as those which exist between rocks of different classes. The strength varies in no ratio with the resistance to wear. So, too, rocks may be tough and yet have no re-cementation qualities in their dust, but the inspection of the table below will show that the volcanic rocks in the main have the highest resistance; the limestones come next in rank. It will be remembered that the results of the tests which are high, correspond to material of good quality, and those rocks whose values are above 20 in cementation and 17 in wear are excellent. Those having co-efficients which are below six are poor. With this general statement it will be recognized that the highest grade of limestone shows a value less than the lowest of the trap rocks; with the granite and schist between the two, the gneisses and sandstones at the bottom. While this is a general statement and holds true for these types of rock, individual specimens or isolated deposits of one or the other may have a higher or lower grade. It is safe, where the nature of the travel and the equipment of the road office will admit of it, to employ trap rock in preference to any of the others. There is plenty of it in the State, and if the railroad transportation rates are made reasonably low, it could be laid down with advantage anywhere in the State. When, however, a closer economy must be exercised, at least in first cost, it would be advisable for the road master to make a test of the several available road materials and determine with the local conditions which will prove the most durable. Indeed, it would be safer if all selections of road covering were deferred until tests had been made of the product of the particularly quarry from which it is intended to be removed.

Stones.	Coefficient of wear.	Cementation coefficient.
Diabase, trap, Chester county,	23.40	13
Diabase, trap, Massachusetts,	16.02	23
Diabase, trap, Frederick county, Md.,	22.10	16
Diabase, coarse, Massachusetts,	9.28	34
Diabase, fine, Massachusetts,	20.33	62
Diabase, Massachusetts,	16.79	14
Gabbro, Rockhill, Pa.,	17.46	12
Gabbro, Baltimore county, Md.,	19.20	4
Gabbro, Hartford county, Md.,	12.70	6
Diorite, Cecil county, Md.,	12.00	1
Granite, Massachusetts,	9.77	12
Granite, Massachusetts,	12.16	16
Granite, Howard county, Md.,	12.00	3
Limestone,	9.38	15
Limestone, siliceous, New York,	12.01	17
Limestone,	8.26	10
Limestone, Helderberg,	9.00	30
Limestone, Ligonier, Somerset county,	10.00	25
Limestone, Trenton, Franklin county,	6-16	7-18
Schist, Massachusetts,	12.21	11
Schist, New Jersey,	8.04	27
Sandstone, Triassic, Maryland,	7.00	28
Sandstone, Catskill, Maryland,	12.30	18
Sandstone, Medina, Massachusetts,	17.48	6
Sandstone, Oriskany, Maryland,	7.90	1
Conglomerate, New Jersey,	11.57	12
Slate, Massachusetts,	8.48	29
Chert, Missouri,	8.35	7
Slag, Howard county, Maryland,	9.00	2
Field stones, Massachusetts,	8.5-14	7-20
Marble, Massachusetts,	7.20	8

Below will be found a table quoting the results of tests for wear upon various rocks, standardized by the French system. The highest and the lowest figure obtained for each class of rock are given. A table is also appended furnishing the results of tests made upon the several varieties of rock for resistance to crushing, the ratio of absorption and the influence of frost.

Kind of Stone.	Highest Result.		Lowest Result.	
	Coefficient of wear.*	Coefficient of wear.*	Per cent. of wear.	Per cent. of wear.
Diabase, trap,	30.40	1.31	9.28	4.31
Granite,	21.16	1.90	8.41	4.76
Felsite,	19.91	2.01	12.30	3.25
Gneiss,	23.02	1.73	5.01	7.98
Limestone,	17.20	2.33	6.31	6.34
Schist,	12.52	3.19	4.87	8.20
Quartze,	20.34	1.97	9.07	4.41
Field stone, erratics,	19.19	2.08	5.43	7.30

*On the French system.

WHAT IS THE BEST MATERIAL TO EMPLOY?

Selection of Stone.—The road master must select material within his own district which will offer the highest resistance to wear and possess the strongest cementing material. These are the properties demanded. The formation which contain the rocks best capable of supplying this demand will be selected, provided they can be delivered cheap on the ground and rolled into place with the equipment he has at hand. It has been seen that no substance shows an exceptional quality in all the tests. No material stands the superior of all the others in the lines in every road-making essential. Hence, it is not easy to name a rock which will have universal commendation as the best road surfacing. In no instance does a given rock show the same approximate rank in all its properties. A certain stone may be superior in strength, but very weak in the elements that contribute to the re-cementation of its broken particles. Another

stone may be so soft as to produce, under travel, more dust than can serve as a cement and yet it joins well. There appears to be no relation between the findings of the various tests, and no clue has traced between the abrasive strength of the stone and its re-cementing qualities. These are independent factors in the value of the stone: The first depending upon the internal constitution and toughness of the minerals, and the second upon the existence of a soft mineral of iron and lime. The physical inspection with a lens or a microscope affords the best clue to these factors. How they are to be rated in a final determination of the merit of the stone is a matter for each highway builder to fix. He has a considerable body of literature to refer to, and will find therein many statements regarding the utility of road metals which are at variance with one another. This naturally arises from the difference in the value assigned to the influences which the cost of the several available substances may have as compared with their co-efficients of wear, their relative binding powers, the amounts of residual dust and the nature of the road machinery equipment which is available.

Undoubtedly the order of excellence in road materials, independent of other issues, is trap rock, vitrified brick, limestones, granites, gravels, sandstones and clays. The economic question, however, is not to be ignored, for the nature of the travel, the size of the individual loads and the grades on which the line is to be built demand consideration. Finally, the question of a comparison between high first cost with little subsequent repairs and the low cost of construction, with continual outlay for maintenance is a condition which must be equated to determine the character of the work. Frequently it may be desirable, if not actually necessary, to import material where no stone exists and where it is of inferior quality. It may be necessary—as the author believes it is—in the western districts to utilize the inferior shale by cementing it into brick. These are all elements of individual preference and judgment. A proper selection of local stone will lead to more road building than a reliance upon trap as the sole material.

To guide the road master in his selection there will be found within the pages 62 to 80 a table showing the varieties of surface materials which are available within the several townships, and, so far as possible the places where they may be found. Possibly better locations may be revealed, but the table represents the results of the year's inspection and does not pretend to be complete. So many conditions of topography exist in each township and so varied may be the command of every locality for an improved road that the selection of an available quarry may not alway be the best suited for the purposes. It contains, however, sufficient suggestions for most,

if not all, of the townships that no apology need be made for its deficiencies in some localities. Location of the site is a matter of judgment.

It is not always certain that the highest grade of road material as judged by the standard tests is the most desirable. Many engineers there are who will be found to have declared it preferable to haul volcanic rock several hundred miles for use on a road in competition with the local stone in order to secure the best surface covering. Such declarations as these the reader must interpret as assuming that the highest type of road is desired that money and machinery can construct. *The volcanic rock should be employed only when the construction of the road is to be of the perfect type, employing rock crushers, screens, steam rollers and sprinkling wagons.* Such a road would be the pleasantest and safest, next to an earth road. In a locality where such an equipment is not possible or feasible, this character of surface will not prove satisfactory. Again, *such a rock covering is required only in regions of very heavy travel* or for speedways. Numerous instances may be cited in support of this, for example, one from Massachusetts—the Nantucket road—which was made partly with a Hudson river trap, which is an extremely good road ballast for heavy wear. But it was found in this case that the road would not stay down. The materials loosened or unraveled because the traffic was insufficient to keep it down, and that, too, notwithstanding an unusual amount of continued rolling. It was finally found necessary to put on limestone screenings, though that rock is far inferior to the matrix which was used. The French District Commissioners also quote in their reports similar experiences where a hard superior rock has been incapable of holding its own when subjected to a light travel only. In Chester county, however, trap covering gives better satisfaction than brick paving, considering everything.

The Best or a Good-Enough Road.—There are two conceptions of roads: 1. The ideal smooth surface, capable of carrying any and every load, in good condition always. 2. The good-enough road that represents a fair degree of improvement and is a compromise between the past and the future. This last can be secured, perfect in all kinds of weather, though it may be difficult to convince the average mind of the fact. *A firm macadamized roadbed, solid and dry in all seasons of the year can be built,* at a moderate cost, without a great revolution in our present methods of construction. It certainly would not require the annual expenditure for repairs that is being wasted under our present unbusiness-like road constructions. We have so long negligently accepted the difficulties of travel during seasons of excessive rain, when traffic is even entirely suspended, that we cannot conceive of a simple remedy such as is offered by the pro-

posed improvement. If, instead of leaving the rock dumped loosely on our winter roads, to be compacted, broken or shifted with each wagon trip, we would simply employ broader tires, or a heavy roller to consolidate the mass, the solution is at once reached. We have never heretofore made systematic effort to carry the water from our road surface, nor have we made attempt to avert the injury done by frost. The infernal "breakers" are our sole efforts in this direction. Even they fail. Far less have we done in the direction of preventing the decomposition and dissolution to the rock itself by the destructive agency of water.

It is to be hoped that a new era will soon be established in Pennsylvania that will give to her citizens roads which are as durable as those prepared in adjoining States. The material is at hand, the means have always been furnished and the occasion is as urgent and the returns will be as great as are enjoyed by our more progressive neighbors, if they but grasp the opportunities afforded them.

The following table shows the number of miles of road now in common use in the several counties and the coverings used, as announced by the road supervisors to the State Secretary of Agriculture four years ago. The mill tax rate is an estimate of average reports:

POPULATION, AREA AND ROAD MILEAGE OF COUNTIES IN THE WESTERN AND NORTHERN TOPOGRAPHIC DIVISION.

Counties.	Population, 1890.	Area, square miles.	Linear Miles of Roads.*		Miles of Road per Square Mile of Area.		Approximate road mill tax.	Materials Used as per Supervisors' Reports.
			Natural.	Improved.				
Allegheny,	551,959	757	2,571	148	3.4	.2	7	Sand.
Armstrong,	46,747	612	2,367	140	3.8	.2	7	Sand.
Beaver,	50,077	452	1,262	11	2.9	.0	3	Sand.
Bradford,	59,233	1,162	2,444	1,000	2.1	.9	4	Shale, cobble, slate.
Butler,	55,339	814	1,453	119	1.7	.1	.....	Sand, flag.
Cambria,	66,375	666	1,533	113	2.5	.2	5	Sand, slate, cobble.
Cameron,	7,238	381	213	9	0.6	.0	10	Sand, cobble.
Clarion,	36,802	572	1,484	212	2.5	.3	6	Sand.
Clearfield,	69,565	1,130	1,862	182	1.6	.1	6	Sand.
Crawford,	65,324	1,005	1,708	865	1.7	.8	6	Sand, cobble.
Elk,	22,239	774	456	91	0.6	.1	10	Sand, slate.
Erie,	86,074	772	2,018	820	2.6	1.0	5	Cobble, sand.
Fayette,	80,006	830	2,095	407	2.5	0.5	5½	Sand, lime.
Forest,	8,482	431	369	117	0.8	0.2	10	Sand, gravel.
Greene,	28,935	620	1,250	11	2.1	0.0	3	
Indiana,	42,175	828	2,290	93	2.7	0.1	7	Sand, shale, cobble.
Jefferson,	44,005	646	1,186	50	1.8	0.1	4	Sand, slate, flag.
Lackawanna,	142,088	424	831	115	2.0	0.2	8	Cobble, gravel, boulders.
Lawrence,	37,517	376	997	70	2.7	0.2	3	Sand, lime, cobble.
Mercer,	55,744	666	1,781	269	2.7	0.4	3	Sand, cobble.
Pike,	9,412	631	742	120	1.1	0.2	9	Gravel, shale, blue granite.
Potter,	22,778	1,071	1,271	373	1.1	0.3	10	Sand, cobble.
Somerset,	37,317	1,102	2,434	517	2.2	0.4	7	Sand, cobble.
Susquehanna,	40,093	828	2,840	715	3.4	0.8	10	Gray, blue, cobble.
Tioga,	52,313	1,124	2,299	923	2.0	0.8	5	Sand, cobble.
Venango,	46,640	658	1,297	374	2.0	0.6	5	Sand.
Warren,	37,585	914	1,424	630	1.5	0.7	9	Sand, shell, gravel, cobble.
Washington,	71,155	889	2,023	139	2.3	0.1	5	Sand, flag, lime.
Wayne,	31,010	747	1,235	235	1.6	0.3	10	Shale, sand, cobble.
Westmoreland,	112,819	1,046	2,564	301	2.5	0.3	4	Sand, slate.
Wyoming,	15,891	403	910	12	2.2	0.0	6	Cobble, shale.
Total,	.....	23,331	49,209	9,180	2.5	.....	.....	

*Columns marked * are obtained from records in the office of Department of Agriculture of Pennsylvania.

POPULATION, AREA AND ROAD MILEAGE OF COUNTIES IN THE MIDDLE TOPOGRAPHIC DIVISION.

Counties.	Population, 1890.	Area, square miles.	Linear Miles of Roads.*		Miles of Road per Square Mile of Area.		Approximate road mill tax.	Materials Used as per Supervisors' Reports.
			Natural.	Improved.				
Bedford,	38,644	1,003	1,934	294	1.9	0.2	7	Sand, lime.
Blair,	70,866	510	784	153	1.5	0.3	4	Sand, lime.
Carbon,	38,624	402	656	3	1.5	0.0	10 up	Sand, shale, cobble.
Centre,	43,269	1,227	1,356	317	1.1	0.3	6½	Sand, lime, flint.
Clinton,	28,685	857	800	119	1.0	0.1	.....	Sand, lime, mountain stone.
Columbia,	36,832	479	723	6	1.5	0.0	4	Sand, lime, slate.
Fulton,	10,837	442	635	49	1.5	0.1	8½	Sand, slate, flint.
Huntingdon,	35,751	899	1,451	141	1.6	0.1	10	Sand, flint, lime.
Juniata,	16,655	407	885	157	2.2	0.4	5½	Sand, lime.
Lehigh,	76,631	364	787	24	2.1	0.1	2¾	Sand, lime, flint, mountain.
Luzerne,	201,203	926	1,604	65	1.7	0.1	9	Sand, cobble.
Lycoming,	70,579	1,213	1,921	52	1.5	0.1	9	Sand, slate, shale, mountain.
Mifflin,	19,996	377	553	102	1.5	0.3	7	Sand, lime.
Monroe,	20,111	595	1,009	76	1.7	0.1	6	Sand, cobble, lime, granite.
Montour,	15,645	140	481	14	3.4	0.1	7	
Northampton,	84,220	382	1,427	25	3.7	0.1	4	Sand, lime.
Northumberland,	74,698	462	1,339	102	2.8	0.2	7	Sand, cobble, lime.
Schuylkill,	154,163	840	1,556	302	1.8	0.3	6	Sand, cobble, flint, mountain.
Snyder,	17,651	317	691	148	2.2	0.4	4	Sand, lime, cobble, flint.
Sullivan,	11,620	434	790	105	1.8	0.2	12	Sand, shale, gravel.
Union,	17,820	315	610	68	2.0	0.2	3	Lime, flint, mountain.
Total,	.....	12,591	21,992	2,342	1.91	.....	.....	

*Columns marked * are obtained from records in the office of Department of Agriculture of Pennsylvania.

POPULATION, AREA AND ROAD MILEAGE OF COUNTIES IN THE EASTERN TOPOGRAPHIC DIVISION.

Counties.	Population, 1890.	Area, square miles.	Linear Miles of Roads.*		Miles of Road per Square Mile of Area.		Approximate road mill tax.	Materials Used as per Supervisors' Reports.
			Natural.	Improved.				
Adams,	33,486	531	1,279	178	2.4	0.3	3½	Sand, flint, iron, granite.
Berks,	137,327	900	2,953	578	3.3	0.6	5 to 7	Sand, lime, shale, granite.
Bucks,	70,615	595	2,107	256	2.8	0.5	3 to 4	Sand, cobble, granite.
Chester,	89,377	763	2,370	249	3.0	0.3	4	Sand, cobble, flint, lime.
Cumberland,	47,271	554	873	188	1.6	0.3	3	Lime, slate.
Dauphin,	96,977	523	934	66	1.8	0.1	3	Sand, cobble, mountain.
Delaware,	74,683	195	659	204	3.4	1.1	4	Trap, flint, cobble, granite.
Franklin,	51,433	756	1,921	623	2.6	0.8	3	Sand, lime.
Lancaster,	149,095	973	2,521	246	2.6	0.3	3	Sand, lime, flint, granite.
Lebanon,	48,131	356	557	130	1.6	0.3	2	Sand, lime, flint, granite.
Montgomery,	123,290	484	1,695	342	3.5	0.7	3½	Sand, slate, flint, lime.
Perry,	26,276	476	1,007	256	2.1	0.5	3	Sand, slate, cobble, iron.
York,	99,489	921	2,922	428	3.1	0.4	3	Flint, lime.
Total,	.....	8,027	22,298	3,744	3.23	.....	.....	

Philadelphia, report 1900, has 1,480 miles of road and streets in use.

Some Remarks on the Distribution of Road Ballast in the Several Counties Arranged Alphabetically. *

Adams County.—Being almost wholly agricultural, the examination of its surface is very difficult. Its geology is complex and consists essentially of gneiss in the four western townships; limestone of medium grade in Conewago, Union and Oxford townships, and sandstones of various colors in alterations of red or grey. In the balance of the county these sandstones occur in layers. Some are calcareous and some of them are coarse grained. Traversing this central belt and manifested on various hills in the county are dolerite and diorite, which are serviceable for both building and road purposes. There is a great array of these traps poured out on the old Triassic floor. The amount is exceedingly large, and if all that is above the main level of the surface were utilized for road purposes, there would be sufficient supply to cover the roads of the entire State, nine feet wide and six inches thick. The material is of high grade for such purpose and would readily bear the cost of transportation to any portion of the State in competition with the best of its local material. Some localities appear to be favorable for production of road metal. Many are inaccessible to railroad.

Allegheny County.—Its surface contains, in the northern portion of the country, sandstones and shale without any limestone; in the southernmost tier of townships a limestone of good quality is to be obtained.

Armstrong County.—With the exception of the iron-bearing limestone, which occurs midway up the banks of the streams emptying into the Allegheny river, and in the hills in Franklin, Pine and Burrell townships, the rocks which are available for road-building purposes are sandstones and glacial gravel.

Beaver County.—Contains no high grade road-building material with the exception of a black limestone which occurs along the Beaver and Ohio River Valleys.

Bedford County.

Bedford—Limestone.

Broad Top—Fire clay and red shale.

Colerain—Limestone in the valley.

Cumberland Valley—Limestone.

East Providence—Red sandstone.

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*The exhibit of road metal and the possibilities of road construction should be of advantage to the residents of the districts who seek definite information regarding the deposits of bedded rocks and the masses of primary rocks suitable for first class roads. The table has been compiled from all sources at hand. The reports of the Second Geological Survey of the State and various other documents have been freely drawn from besides the reports of the Pennsylvania State College School of Mines on "Structural Materials." Personal visits and examination have contributed largely to this table. Fifty-three counties have been traversed, their prominent roads examined and quarries inspected.

East Saint Clair—Excellent shale in the lowlands.
Harrison—Excellent shale in the lowlands.
Hopewell—Excellent shale in the lowlands.
Juniata—Excellent shale in the lowlands.
Liberty—Excellent shale in the lowlands.
Londonderry—Excellent shale in the lowlands.
Monroe—Excellent shale in the lowlands.
Napier—Excellent shale in the lowlands.
Snake Spring—Limestone in the valley.
Southampton—Excellent shale in the lowlands.
South Woodbury—Limestone in the valley.
Union—Excellent shale in the lowlands.
West Providence—Excellent shale in the lowlands.
West Saint Clair—Excellent shale in the lowlands.
Woodbury—Limestone in the valley.

Berks County.—Contains two kinds of gneisses of distinctly stratified schist and syenite. The former furnishes a sandy quartz and a lustrous earth. The syenite weathers to a brownish red clay. The gneiss extends along Perkeomen creek into Hereford township, and southward along the valley between the south base of the South Mountain, and a Triassic sandstone. Some of it is blue and very hard; all of it is very much jointed and closely cleaved. The sandstone is a quartzite, white in color and contains feldspar. It extends along the gneissic hills into Rushcombmanor township. In places it is impure and shaley. The limestones occupy a belt of lowland about three miles wide, extending across the county with the mountain ridges. It varies in color from white to deep black, containing a great deal of organic matter and iron. Most of the limestone is magnesian, hard, flinty, compact and almost crytalline. Lime quarries, from which may be obtained rock waste, are numerous and located centrally in the county and should be able to supply adjoining townships with all that might be desired of a medium grade of road metal. Iron-bearing sandstones occupy the southern portion of the county and furnish fair road surfaces. At various points in Spring, Cumru, Exeter, Douglas and Washington townships along the northern edge of the belt of sandstone, where it comes into contact with the lime, are dike stones in layers having the same traction and dip as that of the sandy rock. The diorite is greenish in color, hard and crystalline, apparently breaking into very small fragments when crushed. This green stone contains a great deal of feldspar and also occurs near the large magnetic iron mines of the district. Boulders cover the region. The hills at Fitztown contain, perhaps, the largest exposure of green stone in the entire county. The distribution of superior road ballast is uncertain. On the other side of the creek is found a very good grade of syenite. South of this point

a fine-grained calcareous conglomerate occurs which would supply good local road covering. The iron mines of the county are numerous and from them should be procured a large quantity of cementing material for the sandstones on the south and the poor road shales on the north.

Blair County.—The ganister mined at Williamsburg is used for the macadamizing of roads about Altoona.

Allegheny—Gray sandy shale in the valley.
Antis—Gray sandy shale in the valley.
Blair—Gray sandy shale in the valley.
Catherine—Limestone.
Frankstown—Red shale, iron ore, limestone.
Freedom—Gray sandy shale in the valley.
Greenfield—Gray sandy shale in the valley.
Huston—Limestone.
Juniata—Gray sandy shale in the valley.
North Woodbury—Limestone.
Snyder—Gray sandy shale in the valley.
Taylor—Limestone.
Tyrone—Limestone.
Woodbury—Limestone, ganister on Piney creek.

Bradford County.—With the exception of LeRoy, Overton, Armenia, Barclay and Monroe townships, suitable road materials may be obtained from the calcareous shales which cover the entire surface. In the townships named as exceptions, the shale is sandy in nature and belongs to the coal measures. Both on account of topography and a poor quality of the clay the road systems of these townships are very poorly developed. At Burlington is an excellent limestone bed of considerable thickness and easily mined.

Bucks County.—With the exception of the townships and their surface named below, the only road stone of any abundance to be found is the various sandstones of the Triassic formation, which are, in the main, unfit for roads, some being calcareous and others conglomeritic. The green stone trap occurring in isolated portions of the county are quite easily accessible and capable of supplying a heavy demand without going too deep in the quarry for the material. Rockhill township has the largest, thickest and longest dike of this material. There is a good supply of trappean material. This should be developed even if the granites are ignored. Microscopic examination does not prove favorable to the sandstones.

Bensalem—Hornblende, gneiss at Oakford; syenite at Willets.
Bristol—Mica-schist, conglomerate, granite at Rockville.
Buckingham—Limestone at Centerville.
Durham—Gneiss, red sandstone, shale, limestone at Durham.
Falls—Mica-schist under the gravel, quartzite, granite.

Haycock—Red sandstone, extensive exposure of trap on the mountain.

Lower Makefield—New red sandstone, gravel, a poor quality of syenite.

Middletown—Mica-schist, yellow to red sandstone, felsite.

Milford—Coarse grey sandstone and trap at Rocky Point.

Rockhill—Red conglomerate, diabase.

Solebury—Grey sandstone, limestone at Center Bridge.

Springfield—Gneiss, red sandstone, shale, limestone at Springtown.

Southampton—Decomposed schist, granite at Feasterville; marble at Neshaminy Creek.

Upper Makefield—Coarse yellow to red sandstone; trap at Brownsburg.

Butler County.—The two northern tiers of townships contain the ferriferous limestone along Slippery Creek Valley, and this is the sole road-building material which is suitable for a hard surface. It is also exposed along Muddy Creek.

Cambria County.—Is very poorly supplied with a road ballast. Its sole reliance is from the clays of the coal measures and the brick locally burned from them.

Carbon County.—This is one of the longest and finest rock sections on exhibitions to geologists in our State.

Cameron County.—No available stone has been found in the accessible regions of Cameron county.

Centre.—This large and important county presents "all the most interesting features of the Palaeozoic geology of the State on a grand scale—a wide expanse of mountain upland, with important coal areas on its top, in the western townships—an uninterrupted Devonian and Silurian valley crossing its middle townships—great anticlinal waves bringing up to the present surface hundreds of square miles of Siluro-Cambrian magnesian limestones, charged with superb deposits of brown hematite iron ore—long parallel symmetrical synclinal ranges of Medina-Oneida mountains separating the limestone valleys—and a labyrinth of these mountains in the southeastern townships, formed by numerous close rock-waves and faulted in several places." Caverns filled with iron ore, on Sinking Creek, near Egg Hill, in Potter township, prove that the great brown hematite pipe ore deposits of Centre county fill depressions in the limestone which were once roofed like other caverns. The townships along Bald Eagle Creek are alone provided with shale of excellent quality, and a good grade of durable limestone on the east side. The townships between Bald Eagle Mountain and the Seven Mountains must depend upon the magnesian layers of limestone which adjoin the black and dark clay shale, which also makes a fairly satisfactory road

covering. In Rush, Snow Shoe, Burnside and Curtin townships the road material is of poor quality except on the tops of the ridges, where a shale of medium quality is to be had.

Chester County.—Has no lack of trap and gabbro covering comparatively considerable areas. It is of the dolerite variety, though it occasionally resembles syenite. Next in value comes the serpentine which is sufficiently abundant to constitute an important road material in the region known as the "Barren." The limestones which are found in the county are free from magnesia, highly crystalline and blue or white in color. Serpentine is abundant, hard, serviceable and extensively mined. Syenite is not infrequent, occurring as a coarse, crystallized white feldspar and hornblende. Next in the order of merit is the red sandstone, which produces a thin, poor soil, but contains, however, elements which will cement when once rolled. The lowest grade of road materials in the county are the mica-schists and feldspar porphyries. They occupy a large portion of the field and are of doubtful utility for road building. The 125 miles of improved roads and 160 of turnpikes are covered with trap over local shale, or native "hornblende."

Birmingham—Serpentine, limestone.

Caln—Limestone at Gallagherville.

Charlestown—Quartzite, conglomerate and syenite at Charlestown.

East Bradford—Mica-schist, limestone, serpentine.

East Brandywine—Syenite, quartzite near Guthrieville.

East Caln—Limestone at West Whiteland; syenite and dolorite at Downingtown.

East Coventry—Sandstone, gneiss, dolorite in the southwest.

East Fallowfield—Mica-schist.

East Goshen—Mica-schist, serpentine at Goshenville; quatzite near Rocky Hill.

East Marlboro—Gneiss, limestone, serpentine.

East Nantmeal—Feldsparic granite and syenite, dolorite near Marsh P. O.

East Nottingham—Chlorite, schist and serpentine at Elkdale.

East Pikeland—Gravel, quartzite, iron ore at Kimberton.

Easttown—Granite, trap, at Smith's Quarry; syenite.

East Vincent—Sandstone.

East Whiteland—Schists, limestone near Malvern and Warren Tavern.

Elk—Serpentine at Hickory Hill.

Franklin—Gneiss. serpentine and limestone.

Highland—Schist.

Honeybrook—Trap at Cambridge; Limestone at Harmony Hall.

Kennett—Syenite and limestone at Kennett Square.

London Britain—Gneiss, quartzite, granite limestone at Nevins, New Garden.
Londonderry—Schist.
London Grove—Quartzite, limestone at West Grove.
Lower Oxford—Chlorite and schist.
New Garden—Limestone at Cedar Spring and McFarland.
Newlin—Schist, limestone, serpentine near Oak Hall.
New London—Gneiss.
New Coventry—Dolorite, trap, sandstone, red shale at Warwick.
Pennsbury—Gneiss and limestone.
Penn—Iron ore and quartzite.
Pocopson—Gneiss.
Sadsbury—Black gneiss at Greenwood Forge; limestone at Pomeroy.
Schuylkiil—Red shale at Phoenixville.
South Coventry—Sandstone, gneiss, dolorite in the southwest.
Thornbury—Syenite, gneiss.
Tredyffrin—Iron ore, serpentine, limestone at Cedar Hall Station.
Upper Oxford—Schist.
Uwchlan—Gneiss, syenite, trap at Windsor.
Valley—Gneiss, quartzite, limestone, near Coatesville.
Wallace—Syenite and conglomerate.
Warwick—Trap at Harmonyville; gabbro at Knauerton.
West Bradford—Mica-schist and limestone near Copesville.
West Brandywine—Conglomerate.
West Caln—Quartzite, limestone, gneiss, syenite at Wagonville.
West Fallowfield—Chlorite and schist.
West Goshen—Schist, serpentine, dolorite in the southwest.
West Marlboro—Mica-schist, limestone near Doe.
West Nantmeal—Quartzite, trap at Perkins; syenite at Loag.
West Nottingham—Mica-schist, iron ore, serpentine.
West Pikeland—Iron ore, feldsparic granite at Chester Springs.
Westtown—Serpentine and trap at Hempills.
West Vincent—Red sandy shale and syenite at Burchrunville.
West Whiteland—Schists and limestone at Roberts.
Willistown—Schists, limestone and serpentine.

Clarion County.—Is mainly overlaid by glacial gravel, some of which along Mill Creek and Deer Creek and near Jefferson City, is of very high grade. The southern townships, tributary to Redbank Creek, have numerous exposure of the ferriferous limestone, which make a good road-building material. That which is mined at West Freedom shows well under the microscope.

Clearfield County.—It is only along the banks of the Susquehanna and Anderson Creek that any suitable gravel has been found. No

limestones have been identified in the county and its main reliance must be upon imported material or artificial product made from the fire-clays of the coal beds.

Clinton County.—In the northern two-thirds of the county through which the Susquehanna passes, the development of high grade road stone does not seem possible; the roads are sandy and no evidence of good gravel has been discovered. In Eagle, Allison, Dunstable and Pine Creek townships is a copious supply of lime and high grade shales, which make excellent road beds. In Porter, Lamar, Logan and Greene townships are limestones and shale of an inferior quality, although suitable for a fair road surface.

Columbia County.

Beaver—Red shale.

Benton—Green shales and sandy limestones cover the township.

Bloom—Limestone along the river.

Briar Creek—Red shales; impure limestone at Berwick.

Catawissa—Calcareous shales; dark blue limestones.

Center—Decomposed limestone, green shale, glacial moraine.

Conyngham—Sandy fire clays and slates.

Fishing Creek—Grey shales; decomposed limestones.

Franklin—Sandstones.

Greenwood—Red and grey shales; limestone at Emillville.

Hemlock—Shales and iron ore; limestone at Ashlandville.

Jackson—Is entirely covered with poor quality of sandstone.

Locust—Sand.

Madison—Red sandy shales; limestone near Ellis.

Maine—Grey shale; impure limestone along the river.

Mifflin—Shales; blue grey limestones.

Montour—Ferruginous shale; limestone at Rupert.

Mount Pleasant—Red shales, gritty limestones near Moranville.

Orange—Shales, red sandstone and glacial bowlders.

Pine—Calcareous shales, green and red.

Scott—High grade limestone, a ferruginous sandstone north of the river.

Sugar Loaf—Red sandstone of poor grade.

Crawford County.—Is overlaid with glacial gravel. Underneath it is a sandstone of a very poor quality. No good road material has been revealed.

Cumberland County.—The famous turnpikes of the central portion of this county are sufficient evidence of the character of the road-building material to be obtained in this county. The limestone is grey to blue; has fine cementing qualities, though a little too granular to be placed among the best of the hard road stones. The iron ores in the banks scattered over the county furnish additional cementing material where desired, and would help to harden the roads in the

shale on the south flank of Blue Mountain. The rocks in the southern tier of townships are gneissic in character, hard but brittle. There is a belt of dolerite trending due north and following the ridge between Silver Spring and Middlesex. There are very extensive limestone quarries in the county and a few places at which granite is mined for building. Rye township has a thick dike revealed at Cove Creek. It is of felsite.

Dauphin County.—Although it is covered with a variety of shales, they are of inferior quality, except at Fishersville, and are, therefore, supplanted for road purposes by the limestone which pass through Swatara and Derry townships, in an easterly direction. The trap, which is in Conewago and Londonderry township, has not been developed, though an abundance of boulders are found on the surface. Near Middleburg, also, is an exposure of gabbro which is accessible, and, of course, satisfactory for road metal.

Delaware County.—The gneiss maintains the same character throughout. It is a hard feldsparic granulite with little mica, but magnetic. The serpentine belt from Lenni to Radnor is quarried in many places. The mineral is far altered.

Aston—Schist, syenite, serpentine and conglomerate.
Bethel—Syenite and conglomerate.
Birmingham—Schist and gneiss.
Chester—Gravel and syenite.
Darby—Gravel.
Haverford—Schist, serpentine, red sandstone.
Edgemont—Schist, syenite, serpentine, trap at Howelville.
Lower Chichester—Syenite on Stony Run and at Linnwood Mills.
Marple—Schist, syenite, serpentine trap.
Middletown—Schist, granite, syenite, serpentine.
Nether Providence—Gneiss, gravel, at Avondale.
Newtown—Mica-schist, syenite and serpentine.
Radnor—Conglomerate, serpentine, limestone, syenite.
Ridley—Gravel.
Springfield—Trap at Marple; gravel at Morton.
Thornbury—Syenite, serpentine; trap at Glen Mills.
Tinicum—Aluvium.
Upper Chichester—Syenite near the creek.
Upper Darby—Gneiss, trap, gravel at Lansdowne.
Upper Providence—Schist, syenite, serpentine, trap.

Elk County.—Along the Little Toby Valley and on Pistner Hill is found a very good sandy shale, making an excellent road material, above which is a limestone suitable for road surface of medium grade.

Erie County.—Has no good natural road stones, but possesses along the Lake Erie front a wide range of shales from which the roads furnish excellent driving material. These sandy materials, with the

shingle along the beach, are the sole dependence of the county. The roads leading into the county seat are occasionally gravelled for a central driveway, about fifteen feet wide.

Fayette County.—Two ridges which traverse Saltlick, Springfield, Stewart and Henry Clay townships contain a medium grade of shale of good cementing quality, though not very durable. Red Stone, Washington and Tyrone townships have another shale quite close to the railroad which would make suitable road covering. Otherwise, the county must depend upon the constant supervision to secure the good natural roads which might be possible in the early spring.

Forest County.—Is, unfortunately, like the other northwestern counties, in possessing no excellent road-making materials near the surface. The banks of the streams traversing it would supply gravel and shale, a mixture of which should be compacted into a good surface. The gravel of course must be that taken from the upper elevations of the banks.

Franklin County.—Contains a wide range of rocks for road-making use. The several turnpikes, which have had nearly a century of use, testify to the serviceability of the native material. The red schists on the east make a strong road surface, as do the limestones of the Cumberland Valley. Both rocks are, however, too brittle for the best service under heavy travel. The best remedy for the dusty condition of these roads would be oil sprinkling. This would be found cheaper and more durable than the prevailing practice of replenishment. The breccias of South Mountain should have further trial for top dressing than that given them unrolled.

Fulton County.—The sole supply of Fulton county for road material comes from Big Cove Creek, though in Pigeon Cove is limestone of better quality. The shale in the middle tier of townships is of lower quality than that which occurs in Wells township.

Greene.—The rolling topography of its surface gives great difficulty in the solution of the problem of improved roads. The pioneer routes along the creeks have been preserved, and construction has been confined to shaping the road surface to an arch. But no rock is available which would make a high-grade ballast. The Fishpot limestone is a very good road metal. It should be more extensively used. A large exposure occurs near Brownsville.

Huntingdon County.—Possesses without doubt the widest range of road materials, though they are all of the medium to inferior grades. The best limestone for road metal is that which follows the phosphate belt in Aughwick Valley and along the Huntingdon and Broad Top Railroad. The shales included between these lines furnish pleasant travel and are identical with, though not so hard as those which

furnish the famous Delaware river drive. Near Nossville and Shade Gap are exposures of good lime, while in Franklin and Warriors' Mark is a hard magnesian limestone making a fair road surface.

Indiana County.—The several anticlinal folds in the rocks have not seriously affected the subterranean topography enough to bring to the surface any road-making materials of high grade. Its surface is composed of soft, decomposible sandstones and shale, out of which little suitable material can be had for permanent roadways without treatment. A large number of brick-making establishments are producing good road pavements that probably will serve some day the highway engineer. The Upper Freeport limestone, in a bed less than ten feet thick, is exposed in several convenient places. Numerous other beds occur, but they are thinner than the Freeport.

Jefferson County.—Has a surface of sandstone and coal measures, with very little prospect for road ballast of high grade.

Juniata County.

Beale—Limestone at Academia.

Delaware—Limestone at East Salem.

Fayette—Red shale and limestone at Oakdale Mills.

Fermanagh—Flint at the Narrows; iron ore and limestone at Banks.

Greenwood—Shale.

Lack—Shales and limestone at Peru Mills.

Milford—Limestone at Patterson.

Monroe—Shale and limestone near Richfield.

Spruce Hill—Shale in the valley.

Susquehanna—Shale.

Turbett—A little shale and limestone.

Tuscarora—Shales and limestone at Reed's Gap and Honey Grove.

Walker—Limestone and red shales at Mexico.

Lackawanna County.—Is covered essentially with sandstone except along the valley of the Lackawanna River, but even here the road-making materials are scarce.

Lancaster County.—The dike stones are of excellent quality and are good for roads which are the seat of heavy traffic. They appear to be conveniently located. The pyroxenite belt, six miles long, is, perhaps, the most extensive field for medium grade of road metal. The serpentine is abundant but rather soft.

Bart—Trap at Georgetown.

Brecknock—Red sandstone.

Caernarvon—Quartzite, limestone, schist, trap on Turkey Hill.

Clay—Limestone and red sandstone at Ephrata.

Colerain—Fissile schists.

Conestoga—Limestone and trap at Safe Harbor and Millersville.

Conoy—Trap, Keller's Quarry; dolorite, Bridgeville; limestone, Haldeman quarry.

Drumore—Gneiss at Penrose Dam; a small dike of dolerite.

Earl—Red sandstone, limestone, trap at Pleasant View.

East Cocalico—Sandstone and a little trap near Reamestown.

East Donegal—Limestone and trap at Mt. Joy borough and Marietta.

East Earl—Conglomerate, blue lime at Weaver's Mills.

East Hempfield—Limestone, trap, on Chestnut Hill.

East Lampeter—Limestone.

Eden—Limestone, micha-schist, dolorite at Quarryville; gneiss at Myres.

Elizabeth—Limestone and red sandstone, trap at Brickerville.

Ephrata—Limestone.

Fulton—Chlorite schists; thick dike at Goshen.

Lancaster—Limestone.

Leacock—Limestone and slate.

Little Britain—Mica-schist in blocks or flags.

Manheim—Limestone.

Martic—Limestone, gneiss on Tocquau Creek.

Paradise—Limestone and gneiss; trap in the southeast corner.

Mount Joy—Red sandstone, limestone at Milton Grove, in Upper Bainbridge.

Penn—Red sandstone and limestone at Manheim.

Pequea—Limestone, slate and schists.

Providence—Ferruginous, mica-schist, limestone at New Providence.

Rapho—Equal halves of sandstone and limestone.

Sadsbury—Micaceous quartzite, slate, limestone on Valley Creek.

Salisbury—Trap at Spring Garden, Peter's Creek and at Belleview.

Strasburg—Limestone.

Upper Leacock—Limestone.

Warwick—Black Limestone at Lititz.

West Cocalico—Trap at Reinholdsville; lime at Schoneck.

West Donegal—Trap at Newville; triassic sandstone, limestone at Reams.

West Earl—Limestone.

West Hempfield—Limestone, mica-schist at Mountville.

West Lampeter—Limestone and slate.

Lawrence County.—The surface is essentially sandstones and conglomerates, with a little shale of good quality near Fayetteville, in Wilmington township and New Bedford, in Pulaski township. The iron-bearing limestone outcrop midway between the flat tableland of the bottom and the valleys.

Lebanon County.—This county is well supplied with satisfactory road metal for macadamizing. It has a limestone of good quality adjoining the shale which passes through Londonderry, Annville, Jackson and North Lebanon. The shales in the central belt of the county are of poor quality to make good dry weather roads; those which have been drained on the sides are often excellent roadways during the fall and winter. The trap occurring near Jonestown is capable of supplying abundant material for improving the important roads of the county, and that which occurs near Coalbrook is sufficiently large and accessible to the railroad to furnish an industry for adjoining districts. It is softer and more readily decomposed than that which occurs in the extreme southeastern portion of the State.

Lehigh County.

Hanover—Shale and slate.
Heidelberg—Shale and slate.
Lower Macungie—Syenite and limestone.
Lower Milford—Red sandstone and syenite.
Lowhill—Shale and slate.
Lynn—Shale and slate.
North Whitehall—Shale and limestone.
Salisbury—Syenite, quartzite and limestone.
South Whitehall—Limestone.
Upper Macungie—Limestone and shale.
Upper Milford—Shale and slate.
Upper Saucon—Red sandstone, syenite and limestone.
Washington—Shale and slate.
Weisenburg—Shale and slate.
Whitehall—Shale and slate.

Luzerne County.—From the point of view of the road maker, this county is not copiously supplied with durable rock. The calcareous shales about Nescopeck and in Huntingdon are the best that is afforded. It is hardly worth while to consider the conglomerates, or the Catskill sandstones north of the river. The materials are prevailingly low in value. They quickly grind to powder. In default of better ballast, the county must rely upon the shales. In the mining communities the roads ought to be dressed with imported screenings from along the Delaware river.

Lycoming county.

Anthony—Shales along Muncy creek; red sandstone on North mountain.
Armstrong—Black marble along the mosquito and red sandstones.
Bastress—A poor quality of soft red sandstone.
Brady—Limestones and shales.

Brown—Red sandstone in the valley; fire clay on the hill.
Cascade—Red sandstone in the valley.
Clinton—Iron, shales and limestone at Clintonville.
Cogan House—Red sandstone in the valley.
Cummings—Red sandstone in the valley.
Eldred—Shale and red sandstone.
Fairfield—Shale and red sandstone.
Franklin—Gray shale.
Hepburn—Shale and red sandstone.
Jackson—Red sandstone in the valleys.
Jordan—Shale.
Lewis—Red sandstone in the valleys.
Limestone—Limestone at Jamestown.
Loyalsock—Shale, red sandstone and limestone.
Lycoming—Shales along Muncy creek; red sandstone on North mountain.
McHenry—Red sandstone in the valleys; fine clay on the hill.
McIntyre—Red sandstone in the valleys; fine clay on the hill.
Mifflin—Red sandstone along Hepburn and Larrys creeks.
Moreland—Gray shale.
Muncy Creek—Shale at Clairstown; limestone at Muncy.
Muncy—Shale and red sandstone.
Nippenose—Red sandy shale and black slate at Fort Antes.
Old Lycoming—Shale, red sandstone and limestone on Pine creek.
Penn—Gray sandstone and limestone at Pennsville.
Piatt—Shale, red sandstone and limestone on Penn creek.
Pine—Red sandstone along the valley; fire clay on the hill.
Plunkett Creek—Red sandstone along the valleys; fire clay on the hill.
Porter—Shale, read sandstone and limestone on Pine creek.
Shrewsbury—Shale and red sandstone.
Susquehanna—Iron, shale and limestone.
Upper Fairfield—Shale and red sandstone.
Washington—Red shales and limestone at Elinsport.
Watson—Red sandstone along Hepburn and Pine creeks.
Wolf—Shale and red sandstone.
Woodward—Shale, red sandstone and limestone on Pine creek.

McKean County.—Is overlaid with gravel covering and sandstone of no value whatever for road purposes. No natural material has been revealed with the requisites for suitable road covering. The sandstone on the surface is very poor for road dressing. The county has a high elevation above the sea. A densely wooded county.

Mercer County.—Only in Pike, Liberty and Jackson townships does there occur road material of even moderate grade of dura-

bility. The balance of the county is devoid of suitable road ballast which is immediately accessible at the surface. Drift covers much of the ferriferous limestone, which, however, is mined at various places.

Mifflin County.

Armagh—Limestone.

Brown—Limestone.

Decatur—Shale at Wagoner; limestone near Decatur.

Derry—Limestone at Logan and Lewistown.

Granville—Limestone.

Menno—Limestone.

Oliver—Limestone.

Union—Limestone.

Wayne—Limestone at Atkinson's Mills; poor shale in the valley.

Monroe County.—Coolbank, Tobyhanna and Tunkhannock are totally devoid of natural road material. The eastern tier of townships possess high grade limestone.

Montgomery County.—This county is, in the main, overlaid by a succession of sandstone layers of various colors, properties which are unsuitable for road making without admixture of cementing material. Norristown uses imported trap rock from Birdsboro, ignoring the local supply. A ridge of dike stone occurring near Green lake and at Sumneytown is quite thick. Another isolated hill of gabbro occurs near the Hill postoffice. With these exceptions, only the townships named below contain road metal of any considerable value. The red shales are unfit for use on main roads but would cover ways of small traffic. The sandstones may be dismissed as unserviceable for first class roads. They grind to powder. The conglomerates seem a little stronger but were not closely examined. The diorite should be exploited. There is an abundance at Conshohocken.

Abington—Mica-schist over limestone; syenite in many places.

Cheltenham—Quartzite, iron ore, granite.

Lower Merion—Gneiss, serpentine, dolorite.

Moreland—Conglomerate, mica-schist, felsite, limestone is said to exist at Somerton.

Plymouth—Quartzite, limestone along the river.

Springfield—Gneiss, limestone, syenite.

Upper Dublin—Quartzite, granite at Gresherton; limestone at Fitzwatertown.

Upper Merion—Slate, limestone, green stone trap.

Whitemarsh—Iron ore, limestone, serpentine at Lafayette; gabbro at Conshohocken.

Montour County.—This small county is almost exclusively overlaid by a grade of red calcareous shales which furnish excellent

road surface. The county as a whole has a fine road system. There is considerable iron in the southern portion of the county and also some extensive quarries of high grade limestone lined along the ridges, as well as at Washingtonville.

Northampton County.—The serpentine of this county is too much decomposed for use on roads. It is like soapstone.

Allen—Limestone and shale.
Bethlehem—Limestone and syenite.
East Allen—Limestone and slate.
Forks—Limestone and syenite.
Hanover—Limestone and syenite.
Lehigh—Shale and slate.
Lower Mount Bethel—Limestone and shale.
Lower Nazareth—Shale and slate.
Lower Saucon—Shale and slate.
Moore—Shale and slate.
Palmer—Limestone.
Plainfield—Shale and slate.
Upper Mount Bethel—Shale and slate.
Upper Nazareth—Shale and slate.
Washington—Shale and slate.
Williams—Shale and slate.

Northumberland County.—Numerous quarries are opened on the Helderberg limestone, whose outcrop is indicated on the topograhic map by heavy dark lines.

Delaware—Dark grey limestone; red shale; otherwise sandstone.
Jackson—Conglomerates and red shale.
Chillisquaque—Decomposed limestone; red shale near Montandon.
Jordan—Red shales; impure black limestones.
Lewis—A thick bed of dark sheily limestone of high grade; black shale.
Lower Augusta—Extensive thick beds of olive gray shales and limestones.
Point—Gray, hard sandstone and flint; limestone crossing it.
Rush—Calcareous shales; ferriginous sandstones.
Shamokin—Calcareous shales; ferriginous sandstones.
Turbot—Limestone on the ridge; chert in the valley.
Upper Augusta—Mainly sands and sandy shales.
Upper Mahanoy—Sandstones, red shale, black lime.

Perry County.—Is the typical unit of the middle district with a complicated structure that offers a great variety of rock formations on the surface.

Buffalo—Chert at Half Fall and Mt. Olive; gray shales, poor limestones.

Carroll—Limestone at Sterrett and Falling Spring; shales at Marysville; iron ore at Bloomfield.

Greenwood—Iron ore, shales at Kings Mill; limestone at Millerstown.

Howe—Shales at Newport.

Jackson—Shales at Bistline; limestone at Blain.

Juniata—Shales at Saville and along the Buffalo.

Liverpool—Shales at Barger; limestone at Pfoutz.

Madison—Shales and limestone at Center Mills.

Miller—Black shale, iron at Pine Grove; limestone at Dicks.

Oliver—Shale at Duncannon and limestone.

Penn—Sandstone along Losh Run; trap in the Cove.

Rye—Iron shale on Blue mountain; trap on Iron Stone ridge.

Saville—Shales in Raccoon and on Buffalo.

Spring—Limestone at Elliottsburg; flint and shale.

Toboyne—Poor shale at Concord.

Tuscarora—Iron shale near Millerstown.

Tyrone—Limestone at Green Park; poor shale.

Watts—Iron shales at Girtys Notch.

Wheatfield—Shale on Dicks Hill; sandstone near Dellville.

Pike County.—The townships flanking the Delaware river alone have natural road making material which is easily procured. Covered roads through Lehman, Delaware, Dingman, Milford and Westfall townships affords pleasant traveling in the State during the summer season. The covering is shale, sufficiently sandy to be compact and containing enough lime to bind well with a moderate degree of moisture. The river road built on it is a pleasant driveway. Naturally the sandy soil supports heavy timber. Ninety per cent. of its area is wooded.

Potter County.—Overlaid by glacial gravel, the banks of the numerous ramifying creeks contain soft shale, furnishing a fair road surface but not a durable one. It is poorly supplied with road stone of even mediocre quality. It is a densely wooded territory.

Schuylkill County.—This county is very unfortunate in not possessing road material of a superior quality, being the richest county in anthracite coal and over which a great deal of heavy hauling is done. The surface is corrugated with ten anti-clinal rock rolls, making the solution of the engineering problem an equally difficult one. The Taxpayers' Association of this county however is largely aiding in the improvement of roads of the region. Over 250 miles have been surfaced, the levy of road taxes have been abolished and excellent roads have been obtained at almost no expense to them-

selves. In some townships the tax levy has been reduced from 10 to 3 mills by making their highways permanent. The townships of Cass, Hazle, Schuylkill, East Norwegian, Rahn, West Mahanoy, Foster, Mahanoy and New Castle have utilized the shale and the local cementing material for covering and compacting their roadways.

Snyder County.—The fossiliferous limestone along South mountain is hard, and being rich in iron affords excellent material.

Beaver—Excellent shale and limestone.
Center—Excellent shale and limestone.
Chapman—Excellent shale and limestone.
Jackson—Excellent shale and limestone.
Middle Creek—Excellent shale and limestone.
Monroe—Excellent shale and limestone.
Penn—Red shale and limestone.
Perry—Excellent shale and limestone.
Washington—Excellent shale and limestone.
West Beaver—Excellent shale and limestone.
West Perry—Red shale and limestone.

Somerset County.—Overlaid by the clays of the coal measures, with the exception of the townships of Allegheny, Northampton and Greenville, the natural road ballast of the county is essentially sandy clays and a red limestone of the Ligonier valley. This limestone is dark in color, tough and hard except in a few localities on the east where it is brittle, and contains considerable clay. This limestone is quarried in numerous places for use in the blast furnaces. Though it occurs persistently under one of the coal seams of the county, it has been traced very carefully and cannot therefore be located on a map or by description. It is an important geological horizon and there is no doubt but that a vigorous search would reveal its outcrop. For enriching the agricultural soils, as well as covering the roads, it would seem desirable that the county authorities would institute an investigation in this direction. The roads of the county furnish comfortable traveling only during the dry season.

Sullivan County.—Is poorly supplied with roads which can afford pleasant or safe traveling during the early portion of the year. Its sole reliance has been sandstone, which, unfortunately, has a low cementing quality. Along Muncy and Loyalsock creeks the sandstone is of better quality. It is very heavily wooded.

Susquehanna County.—With the exception of the lowlands on either side of the Susquehanna river and its tributaries, the surface is entirely one of a light red and gray sandstone, most of which being of poor cementing quality. Boulders of calcareous rocks from which the farm lime is made are unsound for road metal.

Tioga County.—As may be expected, the road system of this county

avoids the white, hard sandstone ridges and is confined to the shale lowlands. The shale is of the same variety as furnishes a good road surface in the eastern portion of the State and possesses very similar qualities for a covering. The travel over the roads being light, it is difficult to judge from inspection of the quality of the surface for heavy traffic. The shale contains a very large percentage of lime; indeed, is more nearly limestone than a clay.

Union County.—The western portion of this county is composed of sandy hills and the eastern and southern of fertile valleys in a road shale with a few small exposures of limestone at Wisetown, Mifflinburg and Lewisburg.

Venango County.—Is covered with shales—mainly of varying qualities, and glacial gravel. Some excellent roads are laid along the river and give satisfaction, even with the heavy travel to which some of them are subjected. The mountain limestone at Centerville is the best native material.

Warren County.—The southernmost limit of the glacial moraine passes through this county, leaving drift and gravel which is serviceable for roads, and the conglomerates in the southern half, which, however, does not make good road surface. The shales immediately under it make good brick and furnish a good cement for the gravel.

Washington County.—The erosion of the elements has produced a topography which is remarkable and particularly troublesome to the highway engineer. The hills are round knobs, with water courses surrounding them, cutting deeply through the formations and exposing a great range of rocks, several of which furnish good building material. The limestones, notably, are good.

Wayne County.—No county in the State is so thoroughly covered with but one formation as is this one, which is overlaid by the pink and gray shaly sandstones of the Catskill formation. The roads traverse it in every direction. The surface is quite uniform in elevation. At the base of North Mountain is a good calcareous breccia, quite suitable for road veneering.

Westmoreland County.—Like Fayette county, is overlaid by the coal measures with their sands and fire clays, and little road metal of superior quality has been found. The Ligonier limestone is sufficient in quantity to supply all local needs. It is found in the hollows on both sides of the valley on Chestnut Ridge and Laurel Ridge. It is siliceous and impure. That at Red Stone is quite thick and strong.

Wyoming County.—No high grade road ballast has been discovered in this county. The most of the road surface being sandy except in Braintrim and Meshoppen townships, where shale prevails. The traffic in the county is not heavy and doubtless the natural materials which are available suffice for the purpose.

York County.—This county possesses a great variety of road building materials. Poor mica-schists extent in a central belt from the Maryland line to the northeast. Green stone traps are abundantly exhibited on the surface in the northern portion of the county; phyllite and slates are found in Peach Bottom, Codorus, Springfield, York and Windsor townships. This material is useless for permanent road construction. The marble along the Hanover Short Line is not strong for road purposes but is of very fine crystalline building material. The townships north of that railroad have red shales and sandstone in abundance, with iron ore in various places and extensive crops of trap. Southeast of the railroad are slates, schists and quartzites in rapid successions of layers. From the point of view of road building, those granite rocks are generally of inferior grade. They are very brittle and excessively micaceous. The great accumulations of trap whose fitness for road making is amply proved, lie so conveniently to rail that the other sources need little consideration. Pyroxenite occurs at Bryansville. At New Park and Fawn Grove is a large exposure of good road metal which may be diabase.

THE INFLUENCES OF TOPOGRAPHY UPON ROAD CONSTRUCTION.

The interdependence of the road metal to be employed on a road surface and the engineering phases of the problem is undoubted. The topography of the county to be traversed is related to the geology of the country and the nature of its underlying formations. The grades and drainage of the foundation depends on the character of the surface material and the method of treating the covering is entirely dependent on the character of the road stones. The construction of a substantial road will therefore be considered only so far as it is related to the local supply of the district of superior or inferior stone.

Topography and the Formations. For the purposes of this paper the area of the State was divided into three topographical districts, with the statement that the nature of the geological formations near the surface determined not only the character and amount of available road metal but also the configuration of the surface. From what has been stated, it is easily seen why the topography of

the northwestern district should reveal essentially a flat tableland with a sandstone cap, sculptured by the rivers in various directions whose banks reveal in their terraces the difference in the resistance of the soft shale and the hard sandstone to the action of the atmospheric elements. So, too, in the middle district, the topography consists of a series of broken parallel ridges of sandstone with water courses following the low lands along the lines of the softer shales and limestones. In the eastern district, to a large degree, the water courses still follow the softer rocks though the geology there is too complex to receive detailed attention in its bearing upon the topography at this time. The most perplexing surface in the State is that presented in Greene and Washington counties.

Sandstones everywhere are on the elevated lands and in so much as their waste furnishes a poor soil for vegetation, but a good one for timber, the regions occupied by them are usually densely wooded and only sparsely cleared for cultivation. There is, however, small occasion for important roads over sandstone regions. Again, the material itself furnishes, as we have seen, a very poor basis for natural road covering and such highways are built through their district are either endured in their natural state or else maintained in proper condition at a very high expense. The road system of Tioga, Lycoming, McKean, Elk and other counties, furnish good illustration of the question in point.

Topography and Alignment. Along the valleys the roads are laid on a better foundation and may receive locally a covering of good stone. They naturally follow the lines of the valleys, intersecting highly cultivated fields. Tables, pages 60 and 61, show the aggregate length of roads in the several counties, and also the population of the same regions. Reducing the number of miles of road to a unit of a square mile in area or to the thousand of population, we will again notice that the roads are most abundant in the more fertile agricultural regions. As has been noted under this table, the cities have been omitted from the discussion and the tabulation. This paper is concerned especially with the country districts of the State, and not with the municipalities which enjoy a sufficiently comprehensive administration of highways without reference to the supply of material or the means of procuring the same by State aid. The farmers in the valleys, however, must have access to their shipping points and communication with the occupants in neighboring valleys, and roads of greater or less importance must necessarily be constructed across the undesirable sand ridges. It is along these lines that good roads are especially difficult.

Topography and Grades. The topography, therefore, imposes problems upon the engineers which are by no means simple. The roads should be planned with reference to the slope of the hills as well as

to neighborhood conveniences, and if it is not desirable to level down the ridges for the width of the traveling way or if the road must be the shortest possible line, the question of grade becomes a serious one. Particularly is this true if these local ways are afterwards to be made portions of the main through routes.

When a road system is to be established, one under State aid, contemplating important arteries of communication across several counties, the topography cannot be ignored and the first work to be undertaken requires familiarity with the elevation of the ground and the distances between the fixed points of the lines. Good maps will be required. The cost of the survey across the territory in the construction of such maps may be high, but the saving in the matter of the roads judiciously laid upon such a map will more than repay in a very short time the expense. Heavy grades may be avoided by even a slight change in the position of parts of the road. Steep grades are also surmountable as, *vide* the National Road in Maryland, over hilly districts, like our middle topographic district. Poor foundation beds may be avoided from the knowledge of the surface rocks. Money is largely wasted if these two elements in road construction are not guarded against. Some writer has ascertained by actual computation that the taxes upon products unnecessarily laid upon a traveler over a heavy grade arising from the injudicious placement of highways, amounts to as much as one-fourth of the total cost of wagon transportation over such roads. The question of improved road construction is then as much one of engineering as of geology. The reduction of the grade of the road profile is expeditiously accomplished when the material removed from the summit is filled into the valley. The cost of the haul and of spreading may be compensated for by the value of the road rock recovered. For every hill is but a mass of hard rock thinly clad with a layer of soil. Rock is therefore to be had in plenty with each hill summit reduced along the road line.

The Engineering Phases. The engineering phases will herein be considered only so far as they affect, or are affected by, the nature of the road surfacing materials. The study of the history of the European roads clearly shows that their construction depends upon the very accurate application of a large body of knowledge which has been obtained either by costly practical tests or by the cheaper laboratory experiments. The only short way to the end is by the institution of a system of surveys and reports with appropriate maps by which our road masters may as quickly as possible be put in possession of the required knowledge as to the nature, locality and mode of treatment of the substances available for use. Herein is found what is perhaps the strongest of the many arguments for the prosecution of the topographic work of the United States geological

survey which is now in progress over the eastern portion of Pennsylvania as well as in other States. It is possible to obtain now, large printed sheets revealing the topographic features and contour lines of extended districts at a very low cost from the Department in Washington. These will furnish the desired information of elevations and distances between points included upon the maps. The easiest grade and shortest line are always sought.

Steep grades impose a serious burden upon road construction by furnishing an opportunity for the rains and freshets in flowing down their course to cause torrential destruction over the surface of the roadbed. The effect of the inclination is also to burden the animals in hauling the load up, or in preventing the rapid descent of the wagon down the incline.

The ideal road should have such an easy grade that a brake will not have to be applied in going down nor will the horses have to hold back. This would indicate a grade of one foot rise in 20 feet of distance as the maximum that is safe or wise, and a minimum of six inches rise in a hundred feet of distance. It is true that spurs and ridges must be surmounted, but it is also true that there is a limiting grade beyond which it is not only unsafe but impossible to go, in planning for grade to an important way. For a continuous trot the grade should not exceed one foot in thirty-six on a smooth road. It is dangerous to attempt to descend at a trot over grades exceeding one in twenty, and horses must be well checked and well held if trotted on one in thirty, but down one in forty, brakes need not be applied. Horses cannot for long, trot up a grade of over one in twenty-two.

The mean tractive force of an animal is about one-fifth of its weight. It can be demonstrated that the resistance which is offered by the weight of a load to being pulled up an incline increases with the angle of the slope. To overcome this resistance it will be necessary for the horse to exert a power at least equal to that amount. Should the slope have one foot of rise in a hundred the pull is 1-100 of the weight; that is, a horse must exert a pull of 20 pounds to move a short ton up this incline (having no regard for the moment to the nature of the road surface); on a pitch of one in ten, the tug at the straps must be at least 200 pounds to raise the ton. On the latter grade, therefore, with a perfect road surface, a normal horse would be incapable of raising a ton-load or of holding back against it on the descent, without serious injury to the surface or without over exertion. The maximum or the minimum grade of the road for safety is, therefore, established by the possibilities of the power employed in hauling. On an excessive slope, either the load must be reduced, whether going up or down, or the number of horses increased.

The grade is influenced by the nature of the road surface, which furnishes a limit to the pitch of the road, according to its resistance to traction. A sandy surface offers so high a resistance that on almost any pitch it would be impossible for a horse to pull a load on the level. On a macadamized surface the resistance would be so slight as to hardly reduce the load which a single animal could haul without extra exertion up a grade. For ascending, therefore, a sandy surface should have a flatter grade for convenient travel than a macadamized surface should have. On the descent, a loose sand surface would assist the animal and the brake to prevent a runaway, while on the other hand, on a steep smooth surface a horse must exert an increased effort against the load. Roughly speaking, therefore, a road surface should be smooth at the time of ascent and rough at the time of descent for the best results.

Though both these conditions are impossible to attain simultaneously, engineering practice has decided that the grades should be flatter as the road surface is more perfect. The macadamized road should have a grade not steeper than one in twenty and below this as much as is possible. The horse can haul an ordinary load up this incline without assistance. In important localities, first class macadamized roads should not be steeper than one in thirty; a grade of one in fifty is not too steep for continuous trotting gait, under a standard load on a well paved roadway. Below is given a table showing the number of pounds of tractive force required to move a one ton load at an ordinary walking pace over a dead level surface composed of the materials indicated. It was taken from Bulletin No. 20 of the United States Office of Road Inquiry.

Kind of Road.	Tractive Force.
	Pounds.
Loose sand (experimental),	320
Best gravel (park road),	51
Best clay,	98
Best macadem,	38
Poor block pavement,	42
Cobblestone,	54
Poor asphalt,	26

The accompanying table shows the tractive force which is necessary to pull a one ton vehicle over the best macadamized surface of various grades and the equivalent in lengths of each mile of grade in miles of level road.

Rate of Inclination.	Angle with the level.	Tractive force.	Equivalent length of level road in miles.
	° ′ ″	Pounds.	
Level,	0 00 00	38	1.00
1 in 500,	0 6 53	42	1.10
1 in 100,	0 34 23	58	1.52
1 in 80,	0 42 58	63	1.66
1 in 60,	0 57 18	71	1.87
1 in 50,	1 08 16	78	2.05
1 in 40,	1 25 57	88	2.30
1 in 30,	1 54 37	104	2.73
1 in 25,	2 17 26	118	3.10
1 in 20,	2 51 21	138	3.63
1 in 15,	3 48 51	171	4.50
1 in 10,	5 42 58	238	6.26

Grades and the Rainfall. As the scouring action of freshets flowing over the surface increases with the inclination of descent, it is important to reduce the grade to a minimum whether side drains are built along the traveled way or not. The softer the stones used on the surface the more important becomes the necessity for the diminished grade.

Road Construction.

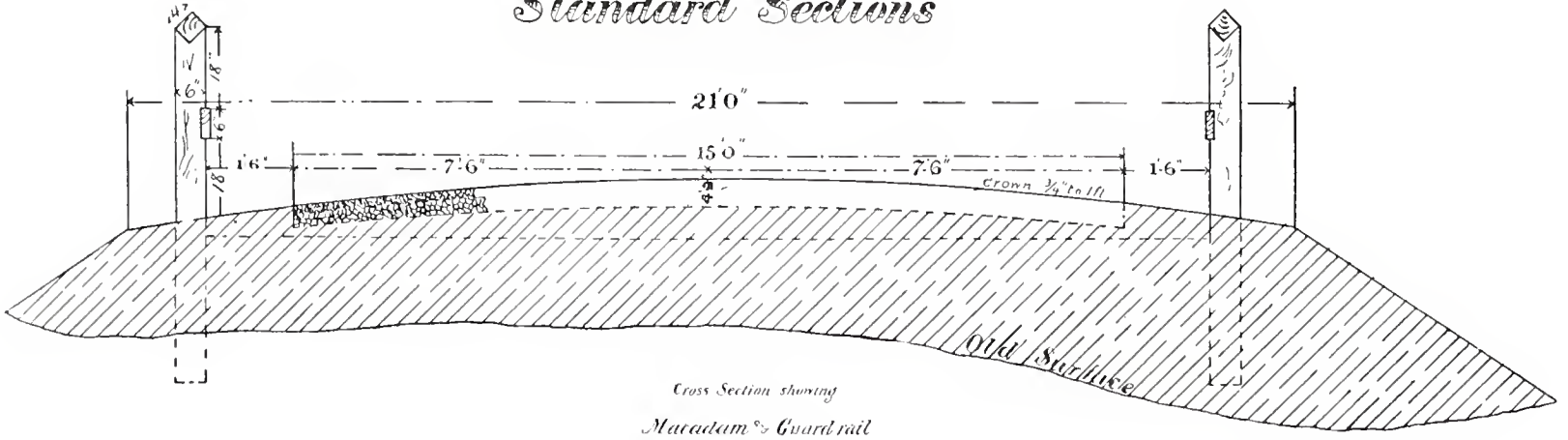
The cross section of the road should be such that the waters will be rapidly carried to the side drains. A crown is therefore built at the centre, the amount depending upon the grade of the road. That which is most desirable below grades of four per cent. (four feet of rise to one hundred feet of distance) is four inches; on grades exceeding four per cent. the height of the crown at the centre should be six inches greater than at the sides. An excessive crown tends to throw all the traffic in one line, and most of the wear would be at the centre, where ruts would soon form. This would defeat the very object of the crown, which is to drain the water promptly to the sides. The less the crown the better satisfaction will it give. Below are two illustrations showing a transverse contour of important roads, the first taken from the report of the State Engineer of New York and the second from the Standard Construction of Massachusetts Engineering Department.

The transverse contour of a vitrified brick pavement would have a total rise not exceeding 1-40. On a gravel road the arching is flat, the rise is 1-30.

The width of the roads to accommodate travel should afford a central roadway, shoulders, ditches and, possibly, a side walk. Confining our attention to the stone roadway proper, it rarely need be more than 12 feet, and in many cases 8 or 10 feet will be sufficient. Where the travel is constant in both directions the stone way should perhaps be 15 feet. The tendency to a single track is so strong that even on a wide roadbed the travelers would confine their route to a very small limit. An examination of the sixteen-foot stoned roads in Massachusetts shows that 11 feet is the mean width of travel, and a width of 12 feet would be ample in the vicinity of the larger towns. In Maryland the width commonly traveled in Carroll, Allegheny and Baltimore counties is between 8 and 10 feet. The writer favors a 7 or 8 foot road as sufficient provided the macadamizing be carefully made. The addition at the sides for shoulders of a few feet in width of good gravel would give a turnout when desired, if firm grass sod is not provided. Experience in Massachusetts demonstrates that the proportion of roadway traveled to that constructed is overestimated.

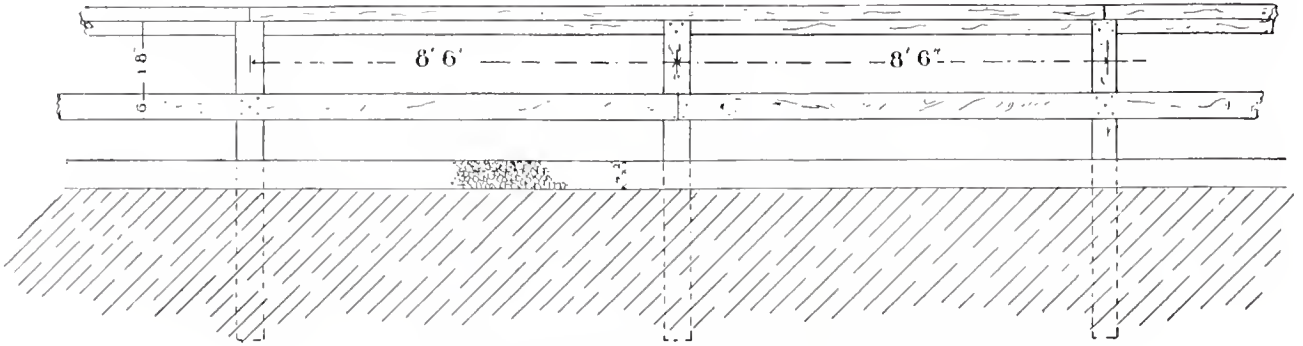
The forms of specifications for stone roads under the State Aid Law of New Jersey are given in the report of Mr. Henry J. Budd, Commissioner of Public Roads, Trenton, N. J., 1897, pages 143 *et seq.*, and those contemplating the construction of important roads will find much valuable information. The report of the Massachusetts Highway Commission, 1897, Appendix F, pp. 46 to 72, contains instructions to assistant division and resident engineers to guide them in their work.

Standard Sections



Cross Section showing

Macadam & Guard rail



Longitudinal section thro centre showing Macadam & rail

MASSACHUSETTS HIGHWAYS.

Sub-drains.—In order to secure a dry foundation, the use of under drains is advised. They are not expensive and not difficult to lay. They may be of cement, tile, pipe or built of blocks of stone into rectangular conduits to absorb and carry off the excessive rains which otherwise would destroy the bed on which the road covering is laid. For sub-soil drains on a grade of six inches in a hundred, the pipe need not be larger than three inches for a length of 1,200 feet, four inches for a length of 2,600 feet, or five inches for a mile of continuous road. Their lower ends will discharge into some natural water course, and if properly laid, should be capable of taking the surplus surface flow, dry the earth above and prevent frost. The steeper the grade, the smaller, proportionately, may be made the pipe line. The tile pipe should not be overburned, warped or black, nor should they be soft and give a dead "punky" sound when struck with a hammer. The cost when laying pipe drains is from five to eight cents per foot for sizes up to and including twelve inches.

Breaking the Stone.—The size to which the stone of the covering is to be broken depends upon its quality and the amount of traffic to which the road will be subjected. The size of stone which makes the best wearing surface would seem to be the one of the largest possible dimensions, while possessing the power to bind and knit closely when rolled into place, and to present a smooth wearing surface. This is on the principle that large stones are stronger than small. Macadam's original rule was one inch in dimension, or three ounces in weight. There has been, however, a great diversity in selection by that which is found to be most serviceable, and to give a smooth roadway with the least expenditure of labor and money. The cost of crushing is, of course, lower as the size is larger, but the larger stones, unless thoroughly rolled, make a rough road. The smaller stone, on the other hand, would require quick renewals. The very common practice is to set the crusher jaws for a one and three-quarter-inch delivery. Larger than this size is certainly mischievous for any variety of stone except the softest. Undoubtedly the size is largely governed by the character of the surface material. Trap rock must be broken to small dimensions for road use to give equally good service with limestone which may be used to a limiting size of two inches.

The following comparative table will show the results of crushing three varieties of materials and the amount of labor involved in the same.

	Trap*.	Granite.*	Limestone.
Cubic yards broken,	3,155	1,785	4,224
Tons, of 2,240 pounds,	4,000	2,142	5,198
Time, hours,	412	198	270
Cubic yards per hour,	7.7	9.0	16
Cost per cubic yard of stone at crusher,	$0.838	$0.37	$0.23
Sizes 2½ inches, cubic yards,	1,618	994	2,490
Sizes 1 inch, cubic yards,	323	.....	562
Sizes ½ inch, cubic yards,	210	427	
Sizes tailings, cubic yards,	1,004	365	1,272

*From the Report of the Geological Survey of Maryland.

The rock crushers can be adjusted for any delivery within moderate limits. When they are set to furnish a given size, say one and three-quarter inches, they will produce considerable finer material. To preserve a uniformity of size in order to secure the most intimate contact with rolling, the big stones and the small stones must be eliminated by screenings. However careful the contractor or engineer may be to procure a uniform delivery of stone, it is the common experience that more material is rejected from the dump pile than is accepted.

In a recent bulletin of the State Secretary of Agriculture is found (page 37) an estimate of the cost of crushing and distributing. The same is estimated at 18 2-10 cents per cubic yard, on a basis of 70 cubic yards per day and 37 7-10 cents for distributing. The hauling is done with two teams and one helper. Trap costs nearly 57 cents per cubic yard for crushing.

As between machine and hand breaking of rock, it is difficult to determine the comparative cost, for local conditions vary to a high degree. There is no difference in the suitability of either variety of broken rock except that perhaps the product will be more uniform from the machine as it would necessarily be screened before delivery. One man can, with a long-handled two-pound hammer, break 2 1-12 cubic yards per day. Rock crushers may be had of various patterns to break from 40 perches a day up.

The thickness of the road metal need be only so much as will support the traffic and no thicker than is capable of being consolidated into an impervious roofing for the foundation. In Massachusetts the average thickness of macadam, which appears to be sufficient for the

heaviest travel on light sub-soil, with a well drained sub-grade, is six inches. On Long Island and in Connecticut the thickness has been reduced from eight to five inches. It is a little heavier in the center than at the sides, and is usually put on in two layers, each having a thickness, when dumped from the cart, of about five inches at the center, and three and one-half at each side. On steep grades a four-inch, well-rolled covering has stood very satisfactorily. On flat grades a thicker layer would be preferred. The harder the rock used for surfacing and the more compactly it is rolled the thinner may be the layer, other things being equal. A thickness exceeding six inches is not required on any except the suburban streets.

The amount of material which would be required for road covering is given in the following table as also the cost per mile for the surfacing material on a basis of payment for it at prices ranging from twenty-five to forty-five cents per square yard laid at the different depths mentioned. This table copied from the report of Commission of H. J. Budd, of New Jersey, 1899, page 255, shows the number of tons of stone required to build one mile of road of the depths and widths specified. This is given on the basis of 3,000 tons of loose stone or 3,500 tons of compressed stone for a road one mile long, 16 feet wide and 8 inches deep.

Width of Road.	Inches depth of rolled stone.	Tone of stone per mile.	Square yards surface in one mile.	Cost per Mile at Prices per Square Yard.				
				25 cents.	30 cents.	35 cents.	40 cents.	45 cents.
8 feet, ...	6	1,312.50	4,693	$1,173 33	$1,408 00	$1,642.66	$1,877 33	$2,112 00
	8	1,750.00	4,693					
	10	2,187.50	4,693					
9 feet, ...	6	1,476.50	5,280	1,320 00	1,584 00	1,848 00	2,112 00	2,376 00
	8	1,968.75	5,280					
10 feet, ...	6	1,640.62	5,867	1,466 66	1,760 00	2,053 33	2,346 66	2,640 00
	8	2,187.50	5,867					
11 feet, ...	6	1,804.80	6,454	1,613 33	1,936 00	2,259 33	2,582 66	2,906 00
	8	2,406.12	6,454					
12 feet, ...	6	1,968.75	7,040	1,760 00	2,112 00	2,464 00	2,816 00	3,168 00
	8	2,625.00	7,040					
13 feet, ...	4	2.132.82	7,627	1,906 66	2,288 00	2,670 66	3,063 33	3,446 00
	6	2,843.75	7,627					
14 feet, ...	4	1,531.25	8,213	2,053 33	2,464 00	2,874 66	3,285 33	3,696 00
	6	2,296.87	8,213					

Settlements for Material by the load have always given trouble. Estimates of quantities made per cart measurements are inaccurate because of the difference in their capacity. We, therefore, suggest

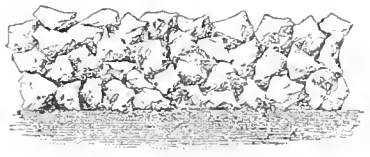
that measurements be made in the pit, previously cross-sectioned with an agreed allowance for shrinkage, if it is not desired to have payment made by the ton. By the cart-load the settlements are vexatious. The report of Massachusetts Highway Commission, page 34, 1900, shows the difference in the capacity of eight double and three single teams used on one of the State roads; the volumes of the carts varied from 36 to 53.67 cubic feet for the double and 22.9 and 28,38 cubic feet for the single carts. The average capacity of the double carts was 1.648 cubic yards and of the single, 0.915 cubic yards. The actual loads hauled were 1.404 and 0.776 cubic yards, respectively, showing a shrinkage of 14.8 and 15.1 per cent. in the two sizes of carts.

The Use of Binding Material.—The crushed stone delivered upon the surface of the road-bed is of irregular shape and generally lacking the uniformity of size. The material can never be laid in close contract so as to exclude voids. These spaces must be filled, whether by the use of smaller particles or by rolling. In any event no amount of rolling will bring these stones perfectly into contact. The volume of voids is a considerable portion of the whole mass. One cubic yard of solid rock weighing 2 1-14 tons will, when broken, occupy two cubic yards of macadam space. The voids must be filled or reduced to prevent infiltration of water. A solid roadway is obtained only by the use of fine screenings and repeated rolling. The smaller the amount of this filler that is placed on the road the better, but it should not be of material softer than the road ballast unless it has a high cementing quality. Hard pan is a material of the last resort. For the coarse, hard granite rocks, sand and granite screenings are advised. When the fragments do not bind well, they creep out of place and break off, thus roughening the traveling way. Hence, some engineers prefer the broken stone screenings. Out of twenty-eight interrogatories, Mr. Oastlar received only eight favoring gravel or sand filled, and seventeen engineers replying in favor of the stone being used.

Rolling.—The use of a filler will not alone make a solid covering, for the fragments must be keyed together. This may be accomplished by repeated travel over the surface of weighted wheels. These latter may be either broad cylinders propelled by a steam engine, heavy rollers pulled by horses, or the ordinary traffic. Unquestionably rolling is necessary, but the conditions which determine a choice of method are local. Generally speaking, however, while the road is in process of construction it is the opinion of the writer that the only circumstance which would justify the road masters in depending upon traffic to make his road is his inability to procure a roller. For, with the other methods which are available, it is possible to apply a heavy pressure over a considerable width of the road-bed, and thus to compact the mass much more uniformly than by the comparatively narrow tire of ordinary wagons. The

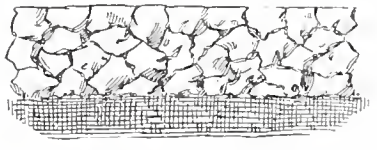
latter would tend to harden only a narrow belt of the road under each wheel. As a matter of fact, however, the loose fragments will move and be dislodged instead of being forced into place, and in consequence will tend to encourage the formation of a rough rather than smooth surface. Until the fragments have been partially cemented, the travel should be restricted to broad-surfaced wheels if a high-grade road is desired. With soft rock, the arguments against a traffic made road have less force, but as the harder varieties of rock are employed the preference is revealed for the steam roller. The horse roller is a compromise between the two. It is not sufficient for trap or the harder varieties of road metal. The pressure which it can exert is much less than that which is obtained from the steam roller.

In contrasting the difference of the serviceability of the horse and steam roller, it is the experience of all with whom the writer has spoken that the latter is preferable though the first cost of the steam roller is higher than for a horse roller—$3,000 against $400. The greater weight on the driving wheels of the latter as compared with the former makes the compression upon the road surface more effective. The pressure per square inch may be only 167 lbs. for the horse—and is from 400 to 700 lbs. for the steam roller. On a hard rock surface like trap, the horse roller is less effective, also, because the animals themselves often exert by their hoofs a pressure greater than that afforded by the roller surface in contact with the rock and they even dislodge loose material which is not easily pressed into place. The horse roller is not capable of doing work upon grades of more than 5 or 6 per cent., while a steam operated roller may be run effectively on a slope of twelve feet in a hundred. More trips must be made by a horse roller than by a steam roller to accomplish the same work, and as it cannot run backwards, like the steam roller, much time is lost in turning it around at the end of each run. The cost of operating a steam roller is between three and four dollars a day less than for the horse machine, and, taking into account that the former is several times as effective because of the greater compression, makes it far more economical than the horse for road surfaces of any kind.



Stone on a macadam road as it appears when spread ready for rolling.

Stone on a macadam road when partially rolled, showing how the roller packs it.



Stone on a macadam road, firmly wedged and packed together. Small stones, gravel, dirt, or sand if mixed with the stone or spread at the surface before rolling, prevent its being thoroughly wedged and packed.

The Volcanic Rocks require two or three times as much rolling to consolidate the surface as do the hardest varieties of limestone. They must get this amount of repeated rolling or else, if opened to the public too soon, the stone will loosen. Care in this regard must be exercised as it is absolutely essential that abundant rolling be given it. In some cases where this has been neglected the trap roads have received a bad name. The fault is not with the rock but with the manipulation. But once hardened and subjected to plenty of travel, the trap roads improve with age while the others deteriorate. The steam roller is recommended where the cost of construction and equipment is not too heavy for the county.

A sprinkling of the surface during the process of rolling aids in a speedy cementation of the fragments. Too much moisture, however, applied during construction would cause a wavy motion during rolling. According to the specifications of the Engineering Bureau of Altoona, the appearance of the wavy motion before the roller determines the time of stoppage of the rolling.

Sprinkling.—The part played by water on crushed stone while undergoing rolling is several fold. The moisture prevents the loss of material which is worn down by the abrasive action; while spreading it permits a more thorough compact of the angular fragments, as it acts much like a lubricant, and in the later stages of the rolling preserves the dust formed during the construction. Its subsequent service during travel is well recognized. In regions where it is practiced, seventy cubic feet of water is the average consumption for 1,000 square yards of surface per day.

The State highways of Massachusetts are divided into eight classes, according to the character of the broken stone which is used as a covering. The character and thickness of the material is indicated below, being determined by the amount of traffic and the weight of the carriage loads.

"State highways are divided as follows, with reference to the broken stone (sizes given are in inches):

"a. All trap rock. Both courses to be $1\frac{1}{4}$ to $2\frac{1}{2}$.

"b. All trap rock. Both courses to be $1\frac{1}{4}$ to $2\frac{1}{2}$.

"c. Local stone other than trap. Bottom course to be $1\frac{1}{4}$ to $2\frac{1}{2}$; top course to be $\frac{1}{2}$ to $1\frac{1}{4}$.

"d. Local stone other than trap. Both courses to be $\frac{1}{2}$ to $2\frac{1}{2}$.

"e. Bottom course of local stone other than trap $\frac{1}{2}$ to $2\frac{1}{2}$; top course of trap rock $\frac{1}{2}$ to $1\frac{1}{4}$.

"f. Bottom course of local stone other than trap $\frac{1}{2}$ to $2\frac{1}{2}$; top course of trap rock $1\frac{1}{4}$ to $2\frac{1}{2}$.

"g. All trap rock. Bottom course to be $\frac{1}{2}$ to $1\frac{1}{4}$; top course to be $1\frac{1}{4}$ to $2\frac{1}{2}$.

"h. Local stone other than trap. Bottom course to be $\frac{1}{2}$ to $2\frac{1}{2}$; top course to be $1\frac{1}{4}$ to $2\frac{1}{2}$."

The Cost of Macadamizing Roads.—The cost of construction of a macadam surface, varying with the nature of the material employed, is between 40 and 80 cents per linear foot of road 16 feet wide, with a thickness greater than 4 inches and a distance of average haul more than a mile, the price will be greater than the above. Undoubtedly, good roads of local material can be laid eight or nine feet wide for a cost of $2,000 per mile. In Massachusetts—including the cost of engineering, salaries, administration—for a 16-foot road-way, the expense reaches $8,505.12 for macadam roads; $6,807.25 for gravel roads. These estimates include material, surfacing and shaping. With culverts, bridges and embankment on side hill, the expense may reach $9,000. Guard rails on both sides of the road, as illustrated opposite page 85, cost $180 per mile. In New Jersey the average of the total mileage of roads built by state aid shows a 16-foot roadway to have cost $4,800.00. The cost of brick pavements, completed with concrete foundation and gutters on either side, from $1.10 to $1.60 per square yard, as reported to me by twenty-six engineers in the State. This includes the excavation at 30 to 40 cents per cubic yard, concreting at 65 cents and sand at 5 cents. The cost of brick varies from $10.00 to $13.80 per thousand, according to locality.

The above figures seem high to the average citizen, but they represent the cost of a perfectly smooth roadway, on which the repairs and the interest are far below the amount formerly levied for road construction. They also represent roads built for exceptionally heavy and speedy travel. For the suburban and country districts the foundation need not be so heavy, nor will curbing and gutters be required and the cost of a 9-foot brick single track road should cost not more than $3,000 per mile. Many of the macadamized roads of Maryland, where the conditions are so much like ours, have been built for less than $2.000 per mile, and in the Cumberland Valley the turnpikes do not exceed $3,000 per mile for construction. One road 12 feet wide and 6 inches thick was laid for $1,000.00 in limestone; another, 14 feet wide and 9 inches thick cost $1,800.00 per mile. Some of the United States object lesson roads have been built for $2,000.00 per mile. One, in New Brunswick, had four inches of crushed stone, another layer of three inches limestone and a top dressing of trap.

The average cost of all classes of roads in New Jersey during 1899 was not far from 45 cents per linear foot of road 8 feet wide and 8 inches crushed stone cover. Those of a consolidated thickness of 4 inches and a width of 8 feet cost about $1,173 per mile.

The initial cost of some broken stone roads in New York was $1,000 per mile. Gravel roads were built for a little more than that. The Telford pavements cost about 75 cents per square yard for material alone.

Oil on Roads.—Dusty roads have been rendered dustless by the use of an oil sprinkler, which is repeated as often as occasion requires. A portable tank, with a sprinkling arrangement like that used for water is moved over the road during the dry season. A light covering of oil is formed which preserves admirably the material which would otherwise be blown or washed away. The method originated with F. W. Mattern, in California, and is very much in vogue. In the western States the idea has been successfully carried out. The first general treatment required fifty barrels per mile of road. Subsequent dressings were made at the rate of twenty barrels per mile. The first was given the road in the spring, the second during July. The experience of many years has proven that the effect of these two doses lasts three years. The boulevard at Bryn Mawr has not been oiled for four years and was still in fine condition.

By the use of oil not only is the dust settled, but its cushion is preserved. The mass becomes hard and is impervious to water because of the repulsion between the two liquids. The effect of frost is diminished and the roadway will remain in good condition, winter and summer. The oiled dirt roads in Chester county were in fine condition this past dry summer.

The Necessity for Repairs.

When this period of road construction is reached, the general idea is that that is all, but one may say here very emphatically, not yet. A new road, like a new watch, wants watching and adjusting to get it into a new permanent shape, and for the first year it wants to be looked after with some care.

The destruction of the surface and the raveling of the road by the action of the forces are inevitable evils with which the road master must combat. In order to preserve the road, he must rely upon the cementing qualities of the rock. A liberal application of sand during the wet season and sprinkling during the dry season of the year are good remedies. The employment by travelers of wide tires would help to preserve instead of destroy the road, and the avoidance of "Indian file" would prevent the formation of ruts. A road well constructed and thus cared for by the citizens will present a smooth surface over the entire roadway. The wear, however, is sure to follow travel and the removal of the debris cannot always be averted. A roadway must, therefore, require replenishment of material, according to the softness of its surface. The wear may be, or ought to be, uniform over the entire width and length. But some portions

of the road are defective or subject to more severe scour and, therefore, wear out faster than the main body. Some of the road stones may be particularly soft, and, again, the foundation may have yielded in some places. Hence, pools or ruts mark the highway even if the material is so well bonded as not to ravel. Repairs will then be necessary, either by touching up stray spots or by recoating the surface according to the judgment and experience of the engineer.

The time when this repair should be made is always one to be determined by the patient endurance of the public or watchfulness of the road master. There seems at the present time to be no regular method, universally adopted in regard to repairs nor the time at which they are to be made nor the extent of such repairs. Engineers differ widely and no rule can be established. That it should be made as promptly as possible is certain, for all dilapidations increase in a heavy ratio after they have once commenced. There seems to be, on the part of the taxpayers, a general apathy in the care of roads, except at such times as the citizen is attempting to make headway with a medium load over a badly kept road. In the past the necessity for repairs is conceded as evidenced by the regular levy of road taxes. Money is voted without protest. But it seems difficult now to educate a community to the need of repairs on a new road. There is sort of a recognized feeling that when it has once been built, that is the end of it. But far from it. Still, it is easier to ingraft into the minds of the commissioners the necessity for construction than the necessity for repairs. This is an undesirable state of affairs, for the repairs are neglected until the traveling way becomes too rough and uncomfortable. Then is created an undesirable impression upon the public mind against the stone road system.

Every argument for making good roads is one for keeping them so. It is an easy matter to make a good macadamized road. The art it based upon principles which every man of common sense can understand and apply, but the question of maintenance requires judgment and some experience in order that the expenditure of money may furnish a maximum of returns.

The animus of the American engineer is to accomplish the largest possible results with the minimum expenditure of time and labor. For this reason it is largely a matter of experience and judgment in determining whether a mere patching of the several weak spots in the surface is sufficient, or a complete re-surfacing of the length of road is necessary.

The average life of a well-made macadamized surface under ordinary country traffic is five years, during which time practically no repairs are required. There have been some well-constructed roads which have kept in good condition ten years without repairs. The question really is: "How far may a six-inch road covering be allowed to wear down without renewal without risking the security of the

foundation?" This will largely depend upon the character and condition of the foundation bed. In France the road masters keep a continual supply of broken rock in neat piles on either side of the roadway, at distances of one-fourth mile apart. Some engineers argue that "A stitch in time saves nine," and maintain a supply of material similarly distributed at convenient places. As the scientific construction of improved roadways is a matter of this decade only, it is not possible yet for us to furnish any accurate data as to the amount of wear on prepared roads, nor have we been able to secure any census of traffic by which to determine wear and cost. The best road system in the world is probably that of France. The amount of rock repairs there used to replenish weak spots was 90 cubic yards per mile for the average traffic over 22,000 miles of road, corresponding to 170 loaded vehicles per year.

As an average taken from twenty-one American cities, it may be well to quote for comparison with that of a macadamized surface: The average life of trap blocks is twenty years; of wood pavements, eight years; of granite, sixteen years, and of brick, fifteen years, without repairs during that time.

Repairs of roads are perennial. The construction is incidental. Every four years on a limestone surface the addition of three inches of covering will be demanded; on trap rock, one inch of additional matter must be supplied every five years. The narrower the roads, the shorter is this period of repair.

The total points in the care of a road are as follows:

1. Keeping the surface of the road free from all deposits, dust or mud and other rubbish.

2. The filling of ruts and depressions due to defective construction of the earth bed or surface deficiencies.

3. Sprinkling in dry weather and rolling.

4. Keeping open the ditches, culverts and water courses.

The quality of material which is necessary to keep a certain stretch of 16-foot road in constant repair varies largely, and it may be stated that a mile of road of good material and under heavy travel would need twenty-five cubic yards per year. This may be disposed in piles containing a cubic yard each, spaced 200 feet apart. A pile six feet long, three feet wide and one and one-half feet high would contain about one yard. This material may be spread over the road surface in the places to be darned and rolled until a smooth, uniform surface is again obtained. Or, preferably, the old road might be picked and loosened before remetalling. In an article before the American Society of Civil Engineers, Mr. C. A. Oastler reported, Vol. XXVIII, page 39, that twenty-six out of twenty-eight prominent engineers from whom he received replies favored the use of picks with the steam roller before putting new ballast on old roads.

The cost of repairs varies with the season and the climate. Where the road is exposed to sweeping winds a raveling increases the expense beyond that which is necessary for the repairs of a road in a moist region. The estimates of cost on improved stone roads vary from $10.00 to $300.00 per mile, as reported by the Department of Agriculture. In the report of the Massachusetts Highway Commission for 1900, the annual amounts expended on roadways and maintenance per mile of finished road are tabulated for the several counties from $29.52 to $119.03, where heavy loads of iron ore pass frequently over the route. In many of the counties, however, the expenditure was larger than the above sum, but were excluded from those mentioned because they included a complete resurfacing for a considerable length of roadway.

In the matter of repairs a proper recoating of the entire surface in a given locality has cost between twenty and twenty-two cents per linear foot for a road sixteen feet wide. For a width of nine feet, and assuming a renewal every five years, this would cost $130.00 per mile on the average. In France the stone roads are kept in perpetually good condition at a yearly expense of only forty-eight cents per inhabitant. In answer to the question, "Is the cost of repairs to a stone road greater or less than the amount expended on the same before improvement?" the general reply was that it was less.

Should the taxes levied for repairs to roads be paid in cash or labor? Judging from the experience of States adopting an improved road system, the answer should be affirmative here. A money system would prove a long step toward road improvement. The Department of Agriculture for this State received, four years ago, replies from more than 3,000 road supervisors over the entire State to the above question, which shows a remarkable unanimity of opinion in favor of a cash mill tax for roads.

The Advantages of An Improved Road System.

Though it is not our object here to point out the improvements of good roads but simply to call attention to the materials that should be used and those which should be avoided and the influence which their employment will have upon the method and system of construction; nevertheless, one cannot refrain from quoting some of the results which are gained by the employment of permanent roadways.

General Roy Stone, in a circular, No. 27, of the Office of Road Inquiry, shows that two-thirds of the vast expenditure of the $946,414,665 for hauling crops to market in the United States is directly chargeable to the bad conditions of our roads. This is on a basis determined by him in reply to more than 10,000 circulars which were sent to the farmers in all parts of the United States. He ascertained

that the average cost of hauling a ton one mile was twenty-five cents, which being twenty-two cents in the Prairie, Pacific and Mountain States, and rising as high as thirty-two cents in the eastern States. Compared with this we have the summarized average cost of hauling the farm products in England, and reported by our consuls there as a little less than ten cents per ton per mile; in Germany the average cost is six and one-half cents; in Switzerland, eight cents. Contrasting these figures with the average cost of haulage which was ascertained by the Maryland Geological Survey as reported for that State, whose topographic conditions are much like ours, it will be seen that we of this State must be hauling our loads at an expense of about eighteen cents per ton per mile more than improved roads would cost us. Again, Professor Eley has estimated that the loss per horse per year on account of bad roads amounts in the United States to $15.00, and figuring on that basis for the State of Pennsylvania, where we have about 618,000 horses, bad roads are costing us $9,300,000 in horseflesh and harness.

The saving of eighteen cents per ton for every mile of haul and $15.00 per horse every year, as may be accomplished by increasing the loads which can be carried to market and by the diminished exertion of overcoming grades and a tractional resistance of soft, rutty surfaces would amount to the annual sum in this State on this basis not far from $14,000,000. In the entire State there are more than 100,000 miles of road, good, bad and indifferent. Most of them have been opened by the common laborers, without the application of any engineering skill. They have followed the pioneer routes located upon any known system. They have been maintained occasionally by abutting property holders during idle seasons of the year. It has cost over $6,500,000* to keep them in such condition as they are. Most of the money was wasted because this sum was put upon the repair of roads poorly constructed and upon improvements which were duplicated the next year. These roads were impassable in portions of the year. It cost more to keep them than if they had been finely macadamized. Of all the great nations—America, the greatest—has actually the worst roads, though her progress in commerce, industries and conveniences of life have been most rapid in spite of them. So, too, Pennsylvania has been far behind her sister States, though she ranks first in the wealth of the natural resources and manufacturing industries. At present the farmers haul their products to market with difficulty and loss. It takes a good part of a life time in driving over the roads, vast sums in repairs to harness and involves loss of privileges of communication. This cannot be measured in dollars and cents, but, nevertheless, represent no insignificant sum. This burden falls upon the

* Report of Hon. J. A. Latta, 1899. This total excludes Philadelphia and Allegheny County's expenditure of $4,821,544.05, on account of streets and roads.

farmers yet, though the farms constitute less than one-fourth of the entire property of the State, that fraction bears the whole cost of building roads. This unjust levy falls also upon the heaviest loser in other respects. It would, therefore, seem equable that the other industries should give aid to road construction and moneys be provided from some source of taxation, such as by State aid. Good roads would be expensive but are necessary for the development of a region, and none is so poor as will not be helped by them. Certainly, an improvement that would double the speed or double the load would bring the individual one-half nearer market, and, with care, enlarge his earning capacity and enhance the value of his land.

A choice between what is desirable and what is essential constitutes the problem with which the highway commissioner must deal. This may be determined by the earning power of the road as a carriage way only. Certain it is that first-class roads may be made luxuries or extravagancies to be dreaded and likely to increase the burden of taxation without a measurable return. Others may be built without reducing the grade properly, or too short for comfortable grade, or over poor supporting foundation or covered with soft local material. But they will not save anything over the former waste in haulage, nor would they materially benefit the region. But any well-made and well-kept road should to some degree be a developer of the district, and how far it will give returns from the expenditure of its construction and maintenance is the main element of the engineer's problem. Advocates of good roads wish for the best. But the road supervisor, while seeking this end, must have regard for the annual taxes which will have to be levied for their construction. Hence, expensive as make shifts, he may be compelled to adopt them even against his will. That improved roads are approved by those living along their lines is unquestioned. That they will be appreciated in our State, there is no doubt. In New Jersey, the Commissioner has great difficulty in determining, out of the numerous applications from the citizens, the order in which the roads shall be built; in Massachusetts the clamor for improved roads has been so great that their construction has proceeded too rapidly for the highway commission to institute any system of allotment. The sentiment is growing in other States and undoubtedly must prevail here shortly. No argument is necessary to show that improved roads have increased the earning power of the districts which they traverse. It is sufficient to quote some figures from the United States Department of Agriculture, which are appended below:

Group of States.	Average haul, miles.	Average weight, lbs.	Average cost per 2,000 lbs. per mile.	Total average cost per ton for whole length of haul.
Eastern,	5.9	2,216	$0 32	$1 89
Northern,	6.9	.....	27	1 86
Middle,	8.8	.....	*31	*2 72
Cotton,	12.6	1,397	25	3 05
Prairie,	8.8	2,409	22	1 84
Pacific Coast and Mountain,	23.3	2,197	22	5 12
Whole United States,	12.3	2,002	25	3.02
Maryland,†	6.7	1,160	26	1 7

*Middle Southern States. †Maryland Geological Survey.

No single system of road management has prevailed throughout this State. There are no continuous boards of supervisors, but the officers change every year. As a consequence, no well-considered plan for road improvement has been possible with this condition of affairs. Though this year may witness one plan of action contemplating improved roads, the next year may find a wasteful method employed of doctoring the old natural roads. No system of alignment is prosecuted either within the county nor of connecting links between the adjoining counties, and no regard is taken of the excessive strain upon the draft animal, which amounts to a very serious grade tax upon the owner. It is to be hoped, for the purposes of developing the stone industry of the State, as well as assisting the industry already established, that a scheme of macadamized roads be inaugurated with State aid to the county levy by which a perfect network of improved roads may be established, not only along the valleys but over the hills and across the State. That the latter is possible, with slight expense, is readily enough shown in the National Road traversing the length of Maryland.

The Secretary of Agriculture of this State has issued a recent bulletin containing a compendium of our State road laws, and in the third volume, 1899, of the Report of the State Geologist of Maryland, pages 333-394, Mr. Harry Fielding Reid has outlined the administration of roads in several states of the Union and many European countries. Bulletins Nos. 1 to 20 of the United States Department of Agriculture also contain the laws governing the management of roads. The New Jersey method of administering State aid for the construction of roads, limits the cost of repairs and construction to one-fourth of one per cent. of ratables for the preceding year. The total amount that can thus be expended in the State, provided the State appropriation is liberal enough to meet it, amounts for this

year, 1900, to $2,167,073.50, and maintained for a few years it would cover all of their leading roads with stone and gravel at a rate of 600 miles annually.

If this rate be applied to the confines of this Commonwealth, there would be available for road service the sum of $7,225,769.29 at one-fourth of one per cent. per year. This would be capable of constructting forty miles of road annually in each county. As it was, three years ago, the sum which was expended for road repairs in the State was $3,622,708 a year, and accomplished little that was permanent. It might have built nearly 1,000 miles of perfect road, which would have required very little for repair and would have returned its cost in short order.

A State Highway Board.—A work of such great magnitude should require careful consideration by a competent board that the work may be done judiciously, and economically, since its results should be permanent. It may not always be wise to employ the material for road covering which is just at hand, and the county officials or the township commissioners may desire to procure material from another district. If the construction is to be left exclusively to them, either they must make individual investigation for suitable road metal or they rely upon some expert source for the information. Each district would then be duplicating the efforts of the other and entailing a great expense that might otherwise be saved to the various divisions of the State by having a common source of information, the State engineer or the advisory engineer of a highway commission. Such an officer or such a board as exists in other States would become the depository for all information gathered upon the subject within the borders of the State and would be best equipped for the procural of data desired by any citizen of the State. Undoubtedly, the selection of such a board would determine the policy of the State in another direction. The construction of highways should be left to the counties, but aid should be given to them in selecting routes or in encouraging the use of the most economical material for surfacing them. Perhaps it might be wise even for the State to aid the counties in building short lengths of model roads and thus bring vividly before the people the comfort and advantage of a well-laid road. In any event, it would seem that the office of road supervisor should be made more than a mere labor boss. It could be placed upon a higher plane and made worthy of acceptance by any engineer. It would become so as soon as the engineering skill is applied to the location and construction of our highways. The tenure of office should be made longer than a working season, in order that the policy may not be too abruptly or frequently altered with each incumbent.

There is no question but that the laying of numerous sections of substantial road along the well-traveled connections between towns, in the interior of the State, will develop a desire for their extension,

with the ultimate results of having a system of improvements that would rapidly reach the branch roads. The region about Haverford College, in Lower Merion township, is an illustration in point where the local roads, improved by Mr. A. J. Cassatt, led to an extension of the work throughout the township. The Commissioner of Roads in New Jersey also remarks upon the feature which is noticeable, as the result of building State aid roads, i. e., the local township or municipal connecting systems of highways were invariably patterned after the main roads; in other words, the advantages would be recognized and the districts would not decrease their individual endeavors by reason of State action. *The habit of road building has been fostered instead of hindered by the State aid.*

Undoubtedly the general scheme for the State should have its inception with the State officials, perhaps within the Department of Agriculture. This cannot be too strongly insisted upon. The main aortas of highway travel should be there determined upon, whether or not the State give financial support to the several counties for their actual construction. The questions of topography, or relative merits and value of the available stone, direction and grade of the several connecting and intersecting portions are too broad for the local authorities to consider.

One matter of moment, which requires delicate as well as careful treatment by the highway commissions of the States now giving aid for roads, has been the selection of roadways to be rebuilt. In order to have a definite plan and ultimate purpose, the commission will be compelled gradually, if not formally, to determine routes and the order of their construction. The first set of roads were those which connected the main business centers. Then, those uniting the smaller and less populous towns with the cities. Next, come those districts remote from rail or water ways. Another group of localities outside of the State limits but adjacent to the Commonwealth, which would have natural outlets in its cities if it were not for the difficulties of the way, should be provided with good roads to the boundary line. Finally, there is presented to the Commissions the question of so grouping the State roads as to afford in the end continuous routes through the Commonwealth.

As soon as the policy has become settled, the tenure of office of the commissioners should provide for a continuous board to preserve the plan, and execute it to the best advantage. The States of Massachusetts and New Jersey are conducting such a system of administration that demonstrates the wisdom and value of supervision from a general center. The anxiety with which the less fortunate residents insist upon establishment of good roads along their fronts and the testimony given by the increased valuation of the lands along the improved ways are sufficient evidence of the estimate to be placed upon the proposed work for Pennsylvania. The saving in cost of haul-

age, the increased profits to the farmer, the greater comfort and speed for the traveler, the diminished cruelty to animals and the improved appearance of the roadways are objects to be attained worthy of the best efforts of a civilized race.

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